Министерство науки и образования РФ

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*Кафедра «Технология конструкционных материалов и материаловедения»*

Л.Б.Аксенов

# ТЕХНОЛОГИЧЕСКИЕ ПРОЦЕССЫ ОБЪЕМНОЙ ШТАМПОВКИ

(термины и определения на английском языке)

Учебное пособие по практической части курса

Санкт-Петербург

2018 г.

УДК 621.983

Аксенов Л.Б. **Технологические процессы объемной штамповки** (термины и определения на английском языке): Учебное пособие по практической части курса / СПб.: 2018, 103 с.

Пособие соответствует ФГОС ВО и предназначено для выполнения практической части курса «Технологические процессы объемной штамповки» (на английском языке) бакалаврами 3-го года, обучающимся по направлению 15.03.01 «Машиностроение», профиль 15.03.01.01 «Машины и технология обработки металлов давлением».

Цель курса - изучение студентами в активной форме основных научных терминов, их значений и возможности употребления при описании теории, технологии и оборудования обработки металлов давлением на английском языке. В пособии содержатся оригинальные тексты (на английском языке) из научных докладов на международных конференциях, учебников, и справочников, представленные в трех частях: «История теории обработки металлов давлением»; «Машины для обработки металлов давлением»; «Технологии обработки металлов давлением». По каждой части курса студенты должны подготовить по одной презентации. В презентациях кратко излагается основное содержание исходного материала, и выделяются ключевые слова. Для ключевых слов приводятся их перевод на русский язык и значение (на английском языке). Из ключевых слов студентами составляется словарь основных технических терминов обработки металлов давлением, с примерным объемом 150-200 терминов.

**Peter the Great St. Petersburg Polytechnic University**

Institute of Metallurgy, Mechanical Engineering and Transport

*Department of Constructional Materials and Material Science*

Leonid B.Aksenov

# FORMING AND FORGING TECHNOLOGIES

(terms and definitions in English)

Study guide for the implementation of the practical part of the course

St.Petersburg

- 2018 -

# CONTENT

# THE ORDER OF IMPLEMENTATION OF THE PRACTICAL PART OF THE COURSE "FORMING AND FORGING TECHNOLOGIES"

(in English)

1. **The purpose of the course**: to learn the basic terms and definitions, their meanings and the possibility of use in describing the theory, technology and equipment of metal forming.

2. **The basis of the course** is the original texts (in English) of scientific papers [1], textbooks [2], and handbooks [3, 4, 5] presented in three parts:
   Part 1: History of the theory of metal forming.
   Part 2: Machines for metal forming.
   Part 3: Technologies of metals forming.

3. **For each part of the course**, each student must make one presentation, the source material for which is determined by a personal task number. The presentation summarizes the main content and highlights the keywords. The explanations given for the keywords. From key words of all presentations should be compiled glossary of metal forming with 150-200 words.

4. To successfully pass the test, each student must:
   - make three presentations on three sections of the course;
   - present to the teacher own glossary;
   - explain the meanings of at least three of the five terms chosen by the teacher.

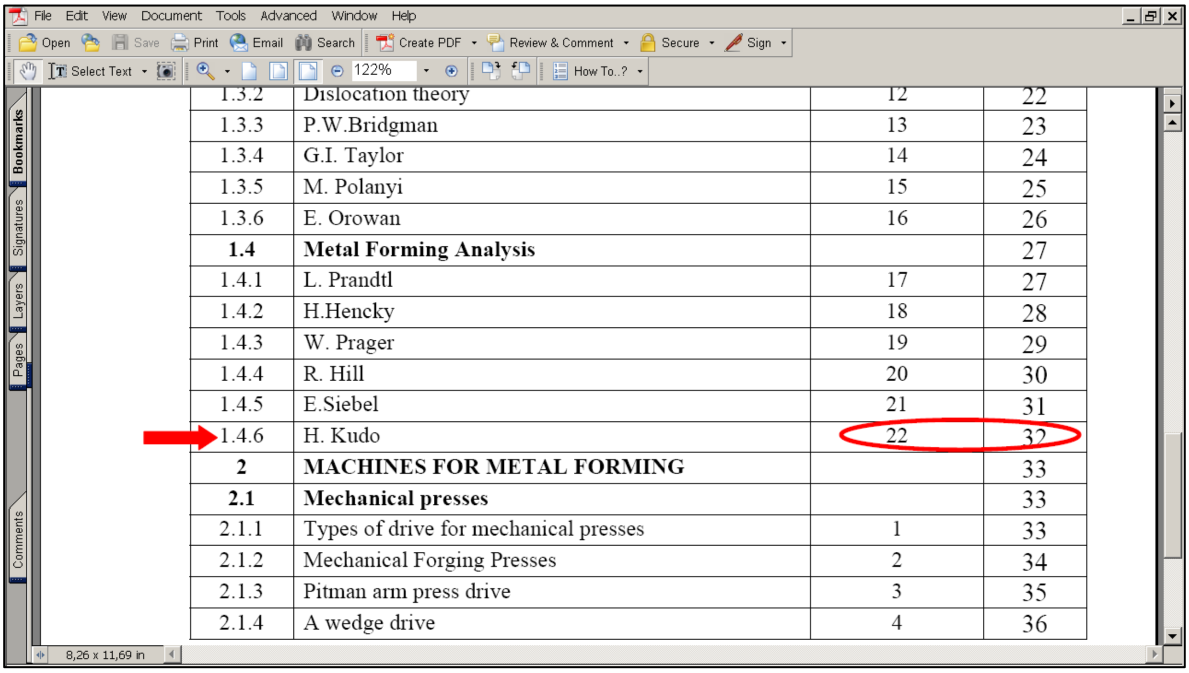
5. **Work in the semester** is based on the following schedule:

| Week semester's | Type of lesson | Part of the course | Task number |
|---|---|---|---|
| 1 | Introductory information, issuance of tasks | | |
| 2 | Consultation | | |
| 3 | Consultation | | |
| 4 | Presentations + consultation | Part 1 | 1 - 6 |
| 5 | Presentations + consultation | Part 1 | 7 - 12 |
| 6 | Presentations + consultation | Part1 | 13 - 18 |
| 7 | Presentations + consultation | Part 2 | 1 - 6 |
| 8 | Presentations + consultation | Part 2 | 7 - 12 |
| 9 | Presentations + consultation | Part 2 | 13 - 18 |
| 10 | Presentations + consultation | Part 3 | 1 - 6 |
| 11 | Presentations + consultation | Part 3 | 7 - 12 |
| 12 | Presentations + consultation | Part 3 | 13 - 18 |
| 13 | Off-schedule presentations + consultation | Parts 1-3 | 1-18 |
| 14 | Off-schedule presentations + consultation | Parts 1-3 | 1-18 |
| 15 | Test | Part 1-3 | 1 - 9 |
| 16 | Test | Part 1-3 | 10 - 18 |

**6. Guidelines for the preparation of presentations**. The volume of presentations for each section is three slides. Presentations should be prepared in PowerPoint. However, make sure in advance that the version in which the presentation is made provides by computer. Presentation design is chosen independently. A dark background does not recommend for slides.

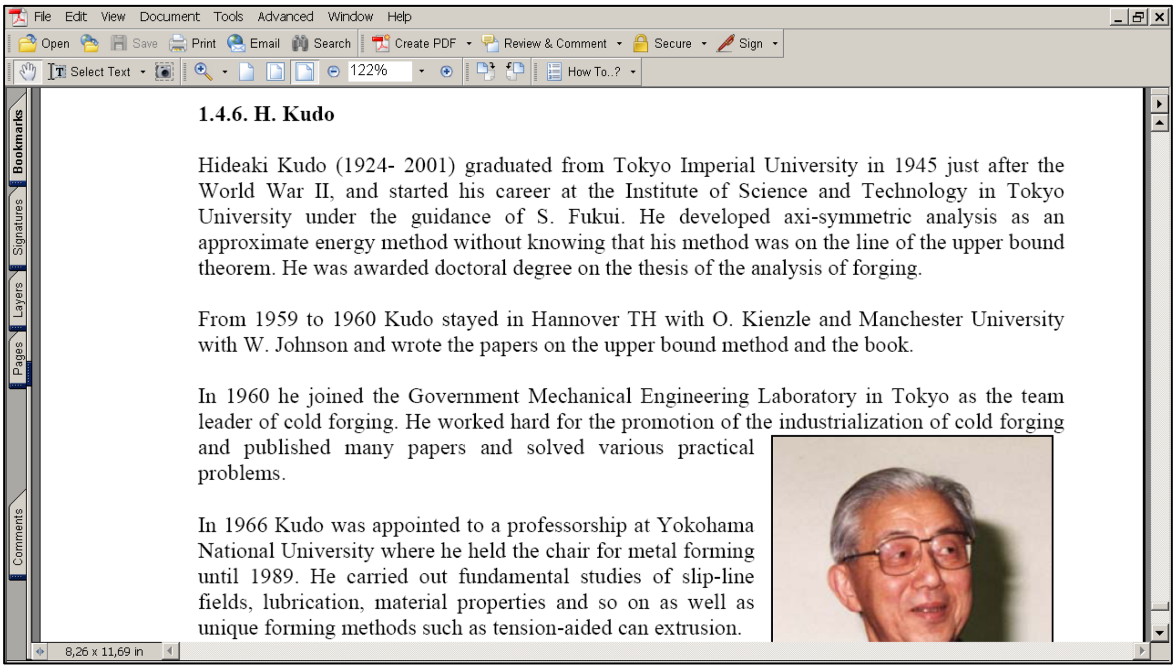
Recommended complete the following steps when preparing your presentation:

***Step 1.*** *To find the topic of the presentation use the task number. For example, the topic "H. Kudo" corresponding to the task № 22 was selected from the list of tasks of part 1 "History and metal forming analysis".*



| | | | |
|---|---|---|---|
| 1.3.2 | Dislocation theory | 12 | 22 |
| 1.3.3 | P.W.Bridgman | 13 | 23 |
| 1.3.4 | G.I. Taylor | 14 | 24 |
| 1.3.5 | M. Polanyi | 15 | 25 |
| 1.3.6 | E. Orowan | 16 | 26 |
| **1.4** | **Metal Forming Analysis** | | 27 |
| 1.4.1 | L. Prandtl | 17 | 27 |
| 1.4.2 | H.Hencky | 18 | 28 |
| 1.4.3 | W. Prager | 19 | 29 |
| 1.4.4 | R. Hill | 20 | 30 |
| 1.4.5 | E.Siebel | 21 | 31 |
| 1.4.6 | H. Kudo | 22 | 32 |
| **2** | **MACHINES FOR METAL FORMING** | | 33 |
| **2.1** | **Mechanical presses** | | 33 |
| 2.1.1 | Types of drive for mechanical presses | 1 | 33 |
| 2.1.2 | Mechanical Forging Presses | 2 | 34 |
| 2.1.3 | Pitman arm press drive | 3 | 35 |
| 2.1.4 | A wedge drive | 4 | 36 |

***Step 2.*** *Find in part 1 material corresponding to a given topic ("H. Kudo").*



**1.4.6. H. Kudo**

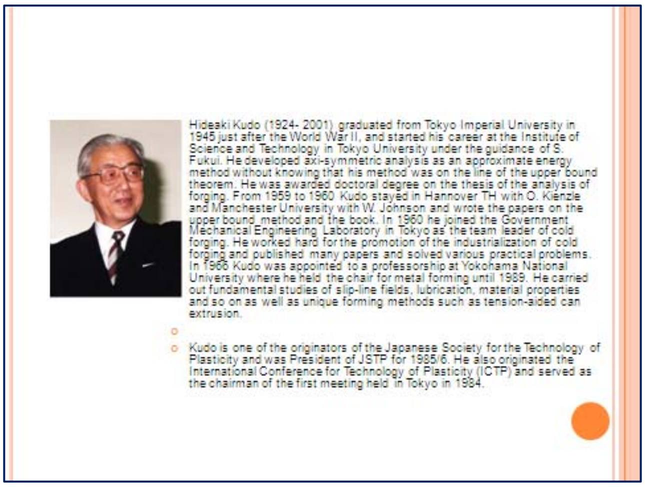
Hideaki Kudo (1924- 2001) graduated from Tokyo Imperial University in 1945 just after the World War II, and started his career at the Institute of Science and Technology in Tokyo University under the guidance of S. Fukui. He developed axi-symmetric analysis as an approximate energy method without knowing that his method was on the line of the upper bound theorem. He was awarded doctoral degree on the thesis of the analysis of forging.

From 1959 to 1960 Kudo stayed in Hannover TH with O. Kienzle and Manchester University with W. Johnson and wrote the papers on the upper bound method and the book.

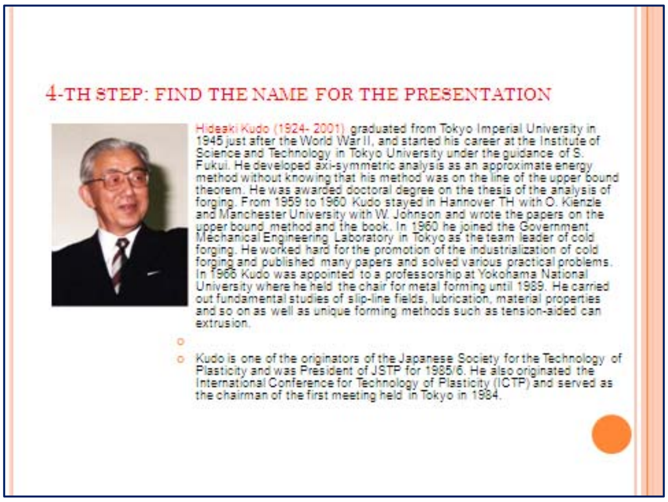
In 1960 he joined the Government Mechanical Engineering Laboratory in Tokyo as the team leader of cold forging. He worked hard for the promotion of the industrialization of cold forging and published many papers and solved various practical problems.

In 1966 Kudo was appointed to a professorship at Yokohama National University where he held the chair for metal forming until 1989. He carried out fundamental studies of slip-line fields, lubrication, material properties and so on as well as unique forming methods such as tension-aided can extrusion.

***Step 3.*** *To move the content of a section to a presentation slide*




***Step 4.*** *To define a name for the presentation.*
*The presentation title should not be much longer than the specified topic.*




***Step 5.*** *To highlight the main content.*
*The selected part (main content) should be short enough, no more than 5-6 sentences or paragraphs, and is fully understood by the author of the presentation.*

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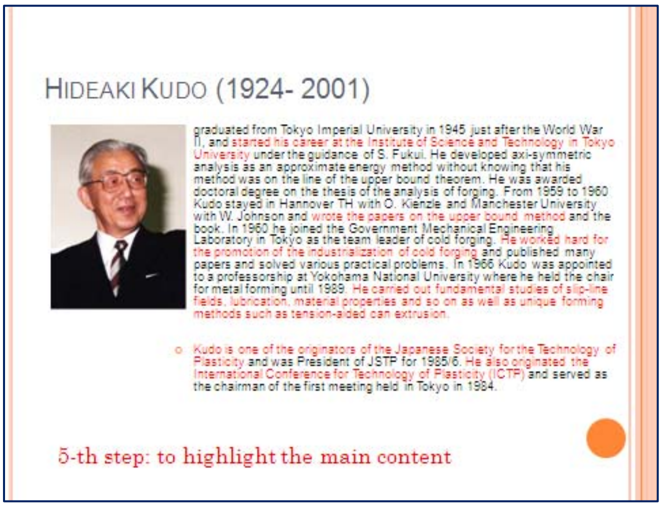
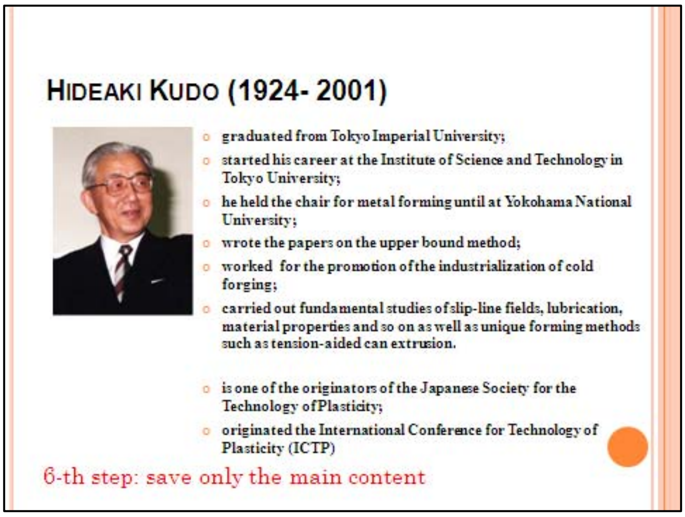
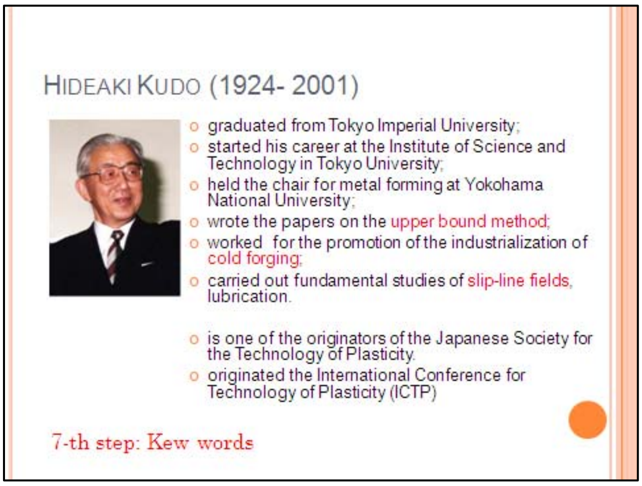


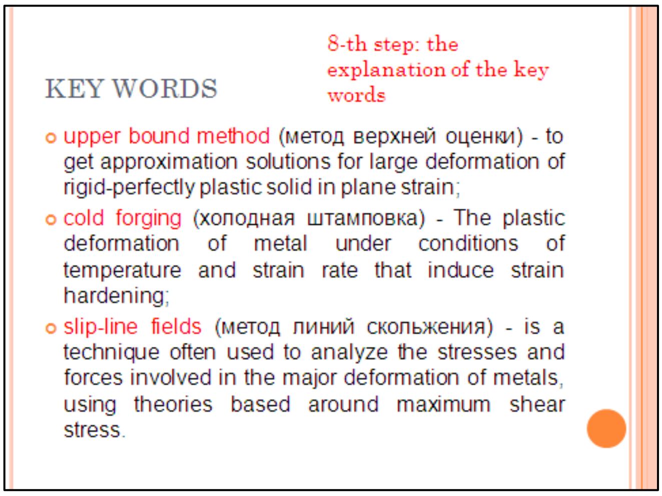
***Step 6.*** *Leave only the selected (main) part on the presentation slide.*
*If there are no illustrations in the source material, they should be found on the Internet and inserted into the presentation.*



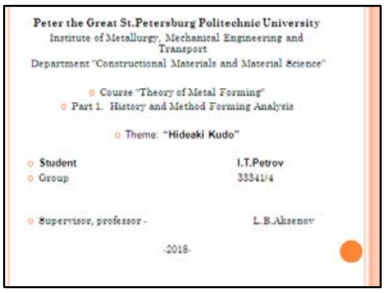

***Step 7.*** *Highlight 3-5 key words or collocations.*
*The key words should be agreed with the teacher.*



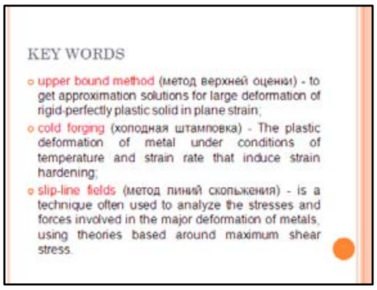

***Step 8.*** *To explain the meaning of key words.*
*The explanation should be as short as possible*



**Step 9.** Complete the title slide to complete the presentation.








The presentation is ready.
Similarly, presentations should be made for the other two parts of the course


1. Сторожев М.В., Попов Е.А. Теория обработки металлов давлением, Изд-во «Машиностроение», М.,1977 .
2. Русско-английский машиностроительный словарь. Электронный ресурс: http://www.classes.ru/dictionary-russian-english-engin.htm .
3. Англо-русский словарь по машиностроению. Электронный ресурс: https://mechanical_engineering_en_ru.academic.ru .
4. Теория обработки металлов давлением (основы) [Электронный ресурс]: учебное пособие по курсу лекций / СПбГПУ, [сост. Л.Б. Аксенов].— Санкт-Петербург, 2013 . URL:http://elib.spbstu.ru/dl/2/3053.pdf .


With the best wishes

Professor Leonid B.Aksenov

# 1. History of Metal Forming Analysis

## 1.1. STRENGTH OF MATERIALS AND PLASTICITY BEFORE THE 20TH CENTURY

### 1.1.1. Early days of strength of materials [1]

Leonardo da Vinci (1452 - 1519) left many texts and sketches related with science and technology although he did not write books. One of the examples he studied is the strength of iron wire, which hangs a basket being poured with sand. The strength of the wire can be determined by measuring the weight of sand when the wire is broken. Unfortunately, the idea and the advancement made by da Vinci were buried in his note, and were not succeeded by the scientists and engineers.

It is generally accepted that Galileo Galilean (1564 - 1642) is the originator of the modern mechanics. In the famous book "Two New Sciences", he treated various problems related with mechanics, including an example of the strength of stone beam. He put his methods applicable in stress analysis into a logical sequence. His lecture delivered in the University of Padua attracted many scholars gathered from all over Europe, and it disseminated the method of modern science.

Robert Hooke (1635 – 1704) published the book "Of Spring" in 1678 showing that the degree of elongation of spring is in proportion to the applied load for various cases. It is generally believed that Hooke came up with the idea of elastic deformation when he carried out experiments of compressibility of air in Oxford University as an assistant of Robert Boyle (1627 – 1691), who put forward the Boyles's law.

### 1.1.2. Torsion test of iron wire by Coulomb

In the paper submitted to the French Academy of Sciences in 1784, C. A. de Coulomb showed the results of torsion test of iron wire carried out with the simple device given in Fig.1.1 He estimated the elastic shearing modulus from the cycle of torsion vibration, and measured the recovery angle after twisting. For the wire of the length of 243.6mm and diameter of 0.51mm, the shearing elastic modulus was estimated to be about 8200kgf/mm2.

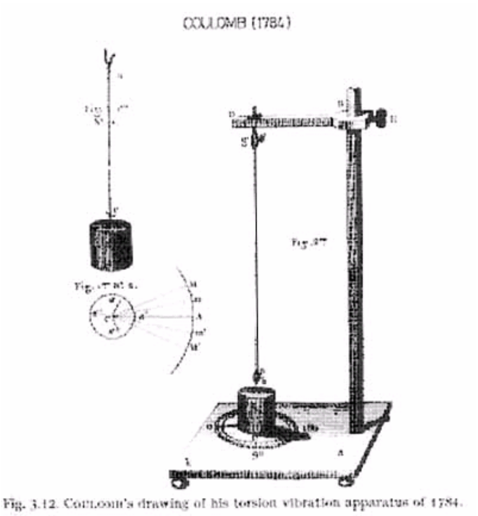



Fig.1.1 Torsion test by Coulomb

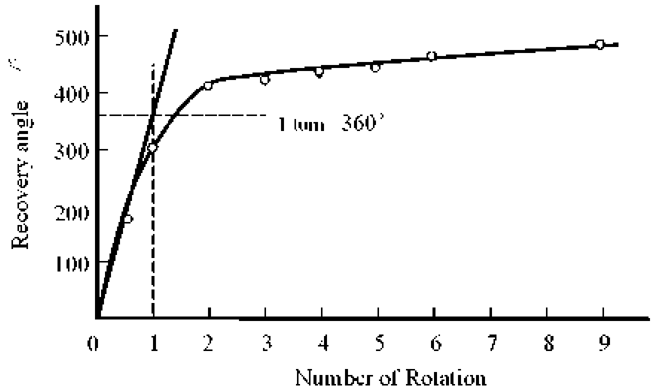
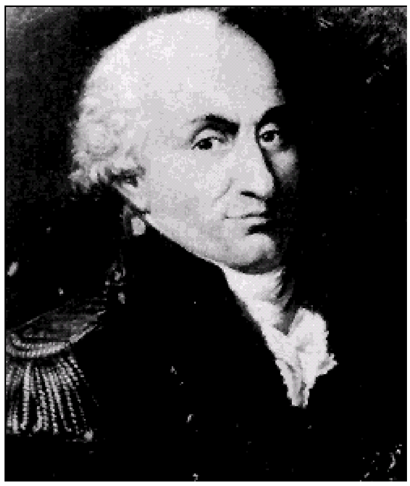



Fig. 1.2. Number of rotation and recovery angle in twisting of iron wire carried out by Coulomb

Fig. 1.2 shows the relation between the number of rotation in twisting and the angle of spring back. When the number of rotation exceeds about 0.5, the angle of recovery becomes smaller than the angle of twisting, and the recovery angle increases only slightly when the number of rotation exceeds two times.

Charles A. de Coulomb (1736 -1808) entered the military corps of engineers after receiving preliminary education in Paris. He was sent to the island of Martinique in the West Indies for nine years. There he studied mechanical properties of materials. In 1773, he submitted his first paper on fracture of sandstone to the Academy. He concluded that fracture of sandstone occurred when the shear stress reached a certain value, similarly to the yield condition due to maximum shear stress.

After returning to France, he worked as an engineer, and continued to carry out research. In 1781, he won an Academy prize on his paper of friction, presently known as Coulomb friction, and in the same year he was elected to membership of Academy.



Charles A. de Coulomb (1736 -1808)

### 1.1.3. Elasticity and stress-strain curve

To determine the elastic constants, measurement of stress-strain relations of metals started, and as an extension of elastic range, stress-strain curves in the plastic range were measured. Fig.1.3 is the stress-strain curve of piano wire measured by F.J.Gerstner (1756 – 1832) and published in 1831. He applied the load to a piano wire of 0.63mm in diameter and 1.47min length with a series of weights. It is obvious that plastic strain is measured after unloading.

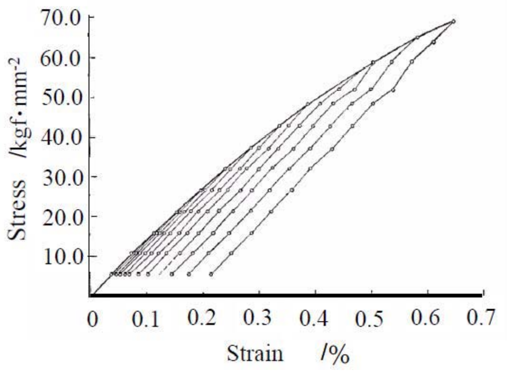



Fig.1.3. Stress-strain curve of piano wire measured by Gerstner

### 1.1.4. H. Tresca

H.E.Tresca carried out experiments of metal forming such as punching, extrusion and compression using some metals, and measured the relation between forming load and ram displacement. He presented a series of papers to the French Academy of Sciences, first in1864. In Fig.1.4 the cross-section of an extruded billed made of 20 lead sheets is given. Tresca was interested in the metal flow as suggested by the title of his first paper 'On the flow of solid body subjected to high pressure', not yielding in material testing.

Tresca assumed that the extrusion force P could be expressed in terms of the shear stress k, and estimated the value of k from the measured forming load of various processes. Because the values of shear stress k estimated from the forming loads dropped in a certain range, he concluded that the metal flow occurred under a constant maximum shear stress.

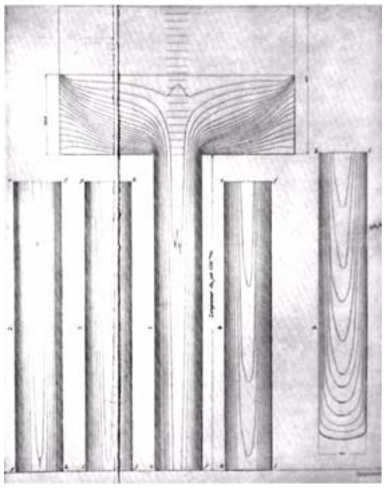


Fig.1.4. Extruded rod by Tresca [2]

Henri E. Tresca (1814 – 1885) graduated from Ecole Polytechnique at the age of 19 in 1833, and sought a career in the design of civil structure. But his ambition was deterred by serious illness, and he spent many years teaching, building and performing tests upon hydraulics. In 1852 he began to work at Conservatoire des Arts et Metie in Paris as an engineer. He suddenly started research work when he was promoted to a major experimental physicist at the age of 50, and soon published many papers. After 8 years concentrated research activity, he was elected to a member of the French Academy of Sciences.

Henri E. Tresca (1814 – 1885)

### 1.1.5. Saint-Venant

When Tresca presented his paper to the French Academy of Sciences, Barre de Saint-Venant (1797 – 1886) was the authority of mechanics in France who was elected a member of the Academy in 1868. After reading the experimental results of plastic flow by Tresca, his attention was drawn to the area of plasticity. In 1871, he wrote a paper on elastic-plastic analysis of partly plastic problems, such as twisting of rod, bending of rectangular beam and pressurizing of hollow cylinder.

Saint-Venant assumed that:
(1) the volume of material does not change during plastic deformation;
(2) the directions of principal strains coincide with those of the principal stresses (now known as total strain theory);
(3) the maximum shear stress at each point is equal to a specific constant in plastic region.

Presently, the last assumption is known as the Tresca yield criterion which is expressed with the maximum principal stress $\sigma_1$, the minimum principal stresses $\sigma_3$ and flow stress Y as:
$\sigma_1 - \sigma_3 = 2k = Y$ .

Although his analyses are not complete from the present view point, it can be said plastic analysis started from this paper.

### 1.1.6. J.Bauschinger

In the second half of the19th century, the Technical Universities in German speaking area became important research centres of plasticity and metal forming. They were established as PS: Polytechnische Schule and then changed to university level TH: Technische Hochschule. Johann Bauschinger (1833 – 1893) graduated from Munich University and became a professor of Munich PS in 1868. He installed a 100 tons tension-compression universal testing machine with the extensometer of his invention, and carried out Fig.5 Bauschinger effect vast amount of measurements of stress-strain relations. He found that the yield stress in compression after plastic tensile deformation was significantly lower than the initial yield stress in tension. Fig.1.5 is the experimental result carried out in 1885, in which compression test is done after tension test up to a strain of 0.6%. It is seen that the initial yield stress was 20.91kgf/mm2 and the yield stress in compression after tensile deformation was 9.84kgf/mm2.

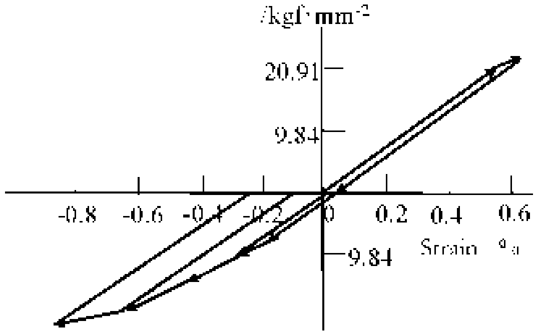



Fig.1.5. Bauschinger effect

## 1.2. YIELD CRITERIA AND CONSTITUTIVE EQUATIONS

### 1.2.1. Progress of research in yield condition

During the 19th century, the maximum shear stress criterion was established by Tresca, Saint-Venant, Mohr and Guest. The yield criterion of elastic shear-strain energy, mostly called as Mises yield criterion, was put forward in the early 20th century. It is written by the following equation with the maximum, medium and minimum principal stresses $\sigma_1$, $\sigma_2$, $\sigma_3$ as:

$$\frac{1}{\sqrt{2}}\sqrt{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_1-\sigma_3)^2}=Y.$$

In 1904, M.T.Huber proposed this criterion [4] although limiting to compressive hydrostatic stress condition. This paper was not known for 20 years by the researchers of plasticity because it was written in Polish language. In 1913, R.von Mises [5] wrote his paper from the view point of mathematics without discussing physical background. In 1924, H.Hencky [6] introduced the Huber's paper and derived the yield criterion of elastic shear-strain energy. In 1937, A.L.Nadai [7] showed that the criterion could be interpreted as that yielding occurs when the shear stress on the octahedral plane in the space of principal stresses reaches a critical value. This idea is now often used in the text books of plasticity because of its simple graphical handling although it has no physical meaning. The difference between the Tresca yield criterion eq.(1) and the Mises criterion eq.(2) when expressed with principal stresses is that the effect of the medium principal stress ( .2 ) exists (Mises) or not (Tresca). This difference was experimentally examined by W.Lode [8] in 1926 with the suggestion by Nadai, and then G.I.Taylor and H.Quinny [9] in 1932. Their conclusions were that the medium principal stress did give influence to the yielding condition for mild steel, aluminium and copper and Mises criterion offered a better pproximation of yield condition.

In 1948 R.Hill proposed a yield criterion of anisotropic material, and since then many researchers tried to express the yielding behaviour of anisotropic materials.

**1.2.2. Constitutive equation**

In the paper published in 1872, M.Levy used an incremental constitutive equation. Von Mises proposed the same constitutive equation because Levy's paper was not known outside of France. Mises considered that the increments of plastic strain components $d\varepsilon_1^p, d\varepsilon_2^p, d\varepsilon_3^p$ were in proportion to the deviatoric stress components $\sigma_1', \sigma_2', \sigma_3'$, where for example $\sigma_1' = \sigma_1 - (\sigma_1 + \sigma_2 + \sigma_3)/3$:

$$\frac{d\varepsilon_1^p}{\varepsilon_1'} = \frac{d\varepsilon_2^p}{\varepsilon_2'} = \frac{d\varepsilon_3^p}{\varepsilon_3'}.$$

In the plastic strain range of a elastic-plastic material, the increments of elastic strain components $d\varepsilon_1^e, d\varepsilon_2^e, d\varepsilon_3^e$ and the plastic strain increments $d\varepsilon_1^p, d\varepsilon_2^p, d\varepsilon_3^p$ should be handled separately. L.Prandl [12] treated this problem for the plane strain problem in 1924, and A.Reuss (Budapest Technical University) showed the expression for all of the strain components in 1930 [13]. For example,

$$d\varepsilon_1 = d\varepsilon_1^e + d\varepsilon_1^p = \frac{1}{E}\{d\sigma_1 - \upsilon(d\sigma_2 + d\sigma_3)\} + \frac{d\bar{\varepsilon}}{Y}\{\sigma_1 - \frac{1}{2}(\sigma_1 + \sigma_3);$$

where $d\bar{\varepsilon}$ is equivalent strain increment which is expressed in terms of the plastic strain increments, and $Y$ is the flow stress.

In the 1960s, when the finite element analysis of elastic-plastic material was under development, expression of the stress increments in terms of strain increments by inverting the above Prandtl-Reuss equation was an important subject. But it was eventually found that R.Hill had already done this work in the book published in 1950.

### 1.2.3. R. von Mises

In the paper published in 1913, R.von Mises [5] manipulated the maximum shear stresses on the principal stress planes:

$$\tau_1 = \frac{\sigma_3 - \sigma_2}{2};\ \tau_2 = \frac{\sigma_1 - \sigma_3}{2};\ \tau_3 = \frac{\sigma_2 - \sigma_1}{2}.$$

It is apparent that simple summation of the maximum shear stresses is always zero:
$\tau_1 + \tau_2 + \tau_3 = 0.$
In the space of the maximum shear stresses, he expressed the criterion of maximum shear stress:
$|\tau_1| \leq k;\ |\tau_2| \leq k; |\tau_3| \leq k;$
which Mises called Mohr's yield criterion.

Then he considered a sum of squares of the shear stresses
$k^2 = \tau_1^2 + \tau_2^2 + \tau_3^2 = \frac{1}{4}\{(\sigma_1^2 - \sigma_2^2) + (\sigma_2^2 - \sigma_3^2) + (\sigma_3^2 - \sigma_2^2)\}.$
While the Mohr criterion is hardly expressed by a simple mathematical equation, the new criterion is easy to handle mathematically, as is often done in mathematical plasticity.

Richard von Mises (1883 – 1953) was born in Lemberg (now Lviv, Ukraine) and graduated in mathematics from the Vienna University of Technology. In 1908 Mises was awarded doctorate from Vienna. In 1909, at the age of 26, he was appointed as professor in Straßburg (now Strasbourg, France) and received Prussian citizenship. There he wrote the paper on the yield criterion.

During the World War I, he joined the Austro-Hungarian army and flew as a test pilot, and then he supervised the construction of a 600HP aircraft for the Austrian army.

After the war Mises held the new chair at the Dresden TH. In 1919, he was appointed as director of the new Institute of Applied Mathematics created in the University of Berlin. In 1921 he became the editor of the newly founded journal "Zeitschrift für Angewandte Mathematik und Mechanik" and stayed until 1933.

With the rise of the Nazi party to power in 1933, Mises felt his position threatened. He moved to Turkey, where he held the newly created chair of Pure and Applied Mathematics at the University of Istanbul. In 1939, amid political uncertainty in Turkey, he went to the USA, where he was appointed in 1944 Gordon-McKay Professor of Aerodynamics and Applied Mathematics at Harvard University.

R. von Mises

**1.2.4. A.L. Nádai**

Arpad L. Nádai (1883 – 1963) was born in Hungary and graduated from Budapest University of Technology, and then studied in Berlin TH getting doctorate in 1911. In 1918 he moved to L.Prandtl's Institute of Applied Mechanics in Göttingen and was promoted to professor in 1923. In 1927, he moved to the Westinghouse Laboratory in the USA as the successor of P.E.Timoshenko. Thus his paper in 1937 on yield criterion was the work in the USA.

In 1927, Nádai published a book of plasticity in German and this was translated into English as "Plasticity – A Mechanics of the Plastic State of Matter" [15] in 1931 as the first English book of plasticity. The characteristic feature of this book is that it consists of two parts, (1) plasticity of metals and 2) application of plasticity in geophysics problems. In1950 the first part of this book was rewritten and published as "Theory of Flow and Fracture of Solids".

A. L. Nádai

## 1.3. PHYSICS OF PLASTIC DEFORMATION

### 1.3.1. Plastic deformation of single crystal

In 1923, P.W.Bridgman invented a method to make single crystal of metal by pulling out of molten metal. Since M. von Laue (1879 – 1960) had already established the method of determining the direction of crystal lattice by X-ray diffraction, the study of plastic deformation of single crystal started abruptly. In 1923, G.I.Taylor and C.F.Elam [16] carried out tension test of Al single crystal (Fig.1.6), and found that plastic deformation occurred by sliding on a certain crystallographic (sliding) plane in a definite (sliding) direction, and the critical shear stress $\tau_{cr}$ on the plane was calculated.

They continued experiments with single crystals of iron, gold, cupper and brass. In Germany, the groups of E.Schmid (1926) and V.Göler and G.Sachs (1927) [18] presented their results of tension test of single crystals.

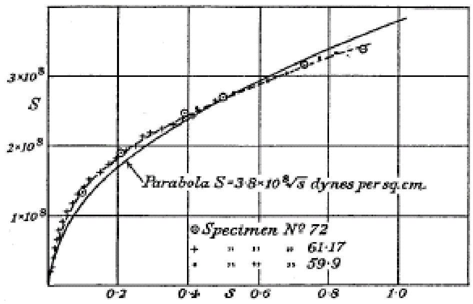



Fig.1.6. Stress-strain curve of single crystal by Taylor and Elam

When a single crystal is plastically stretched, the direction of the crystal rotates as demonstrated in Fig.1.7 due to the sliding over the specific planes, and the sliding planes tend to become in parallel with the stretching direction irrespective of the initial orientation. This means that anisotropy is developed by plastic deformation of polycrystalline metals. W. Boas and E. Schmid (1930) studied the development of anisotropy first.

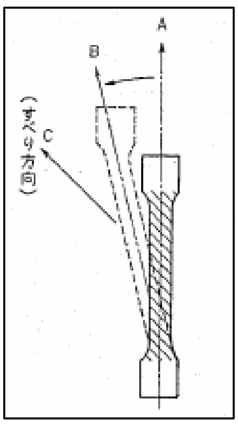



Fig.1.7 Rotation of crystal by plastic sliding

### 1.3.2. Dislocation theory

When the initially polished surfaces of single crystals were observed after plastic deformation, slip bands (Fig.1.8) were observed suggesting that sliding occurred over limited number of sliding planes. Since an extremely large shear stress, 1000 -10000 times as large as the measured critical shear stress, should be needed to overcome the atomic bonding stress, many researchers tackled to find the mechanism of plastic deformation. G.I.Taylor, M.Polanyi, and E.Orowan [24] independently proposed the sliding mechanism by crystal defect, i.e. dislocation, in 1934. Fig.1.9 shows the explanation by Taylor about dislocation in crystal lattice during plastic deformation. The existence of dislocation was proved in 1950s after the electronic microscopy was invented.

Fig.1.8. Slip bands on polished single crystal

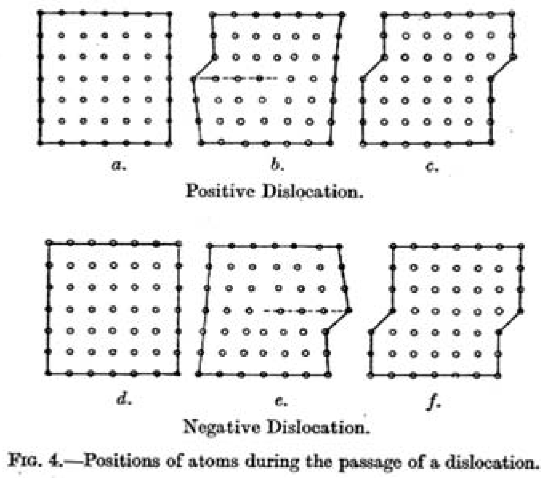



Fig.1.9. Dislocation model proposed by Taylor

### 1.3.3. P.W.Bridgman

The mechanical behaviour of metals under high hydrostatic pressure was mainly studied by P.W. Bridgman during the first half of the 20th century. Although he found that the ductility of metal was remarkably enhanced by pressure as Fig.1.10, he was more interested in the effect of pressure on the stress, which is a little affected by pressure as shown inFig.1.11.

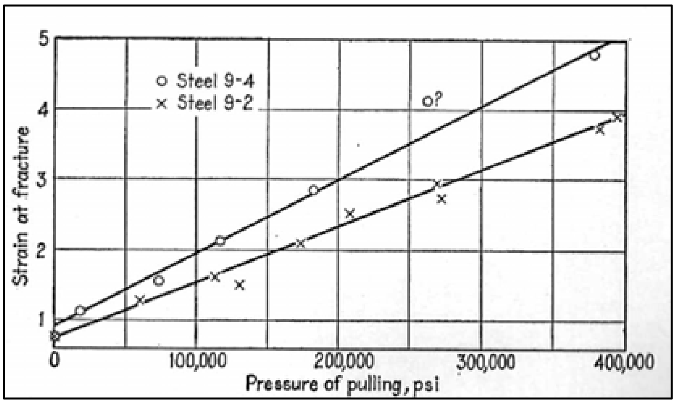



Fig.1.10. Fracture strain and pressure measured by Bridgman

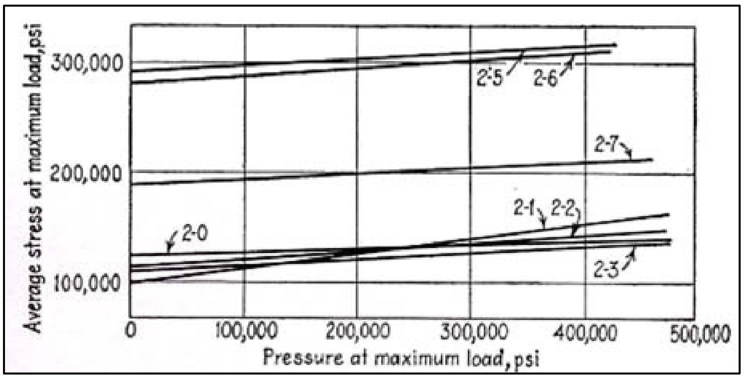



Fig.1.11. Average stress in tension test and pressure measured by Bridgman

Percy Williams Bridgman (1882-1961) studied physics in Harvard University and received Ph.D. in 1908. He was appointed Instructor (1910), Assistant Professor (1919), before becoming Hollis Professor of Mathematics and Natural Philosophy in 1926. He was appointed Higgins University Professor in 1950.

From 1905, Bridgman continued the experiments under high pressure for about 50 years, and published the results on plastic deformation of metals in the book "Studies in Large Plastic Flow and Fracture". He invented a method of growing single crystal and proposed the calculation method of stress state in the neck of tensile test specimen.

P.W. Bridgman

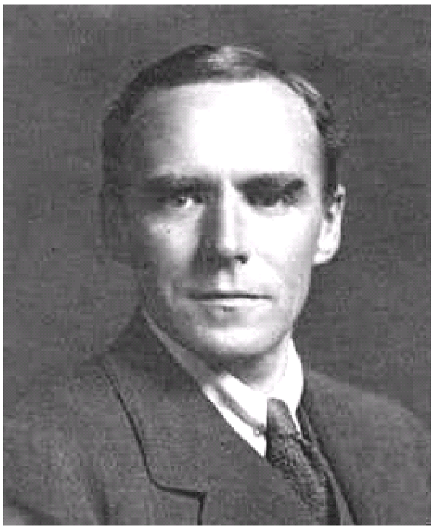
A machinery malfunction led him to modify his pressure apparatus; the result was a new device enabling him to create pressures eventually exceeding 100,000 kgf/cm² (10 GPa). This new apparatus brought about a plenty of new findings, including the effect of pressure on electrical resistance, and on the liquid and solid states. In 1946, he received Nobel Prize in physics for his work on high pressure physics.

**1.3.4. G.I. Taylor**

Geoffrey Ingram Taylor (1886 - 1975) was born in London, and he studied mathematics at Trinity College, Cambridge. At the outbreak of World War I he was sent to the Royal Aircraft Factory at Farnborough to apply his knowledge to aircraft design.

After the war, Taylor returned to Trinity working on an application of turbulent flow to oceanography. In 1923 he was appointed to a Royal Society research professorship as a Yarrow Research Professor. This enabled him to stop teaching which he had been doing for the previous four years and which he both disliked and had no great aptitude for. It was in this period that he did his most wide ranging work on the deformation of crystalline materials which led on from his war work at Farnborough.

During the World War II Taylor again worked on applications of his expertise to military problems. Taylor was sent to the United States as part of the British delegation to the Manhattan project. Taylor continued his research after the end of the War serving on the Aeronautical Research Committee and working on the development of supersonic aircraft. Though technically retiring in 1952 he continued researching for the next twenty years.



G.I. Taylor

**1.3.5. M. Polanyi**

Michael Polanyi (1891 – 1976) was born into a Jewish family in Budapest, Hungary and graduated from medical school of Budapest University. His scientific interests led him to further study in chemistry at the Karlsruhe TH in Germany and got doctorate in 1917.

In 1920 he was appointed a member of the Kaiser Wilhelm Institute for Fibre Chemistry, Berlin, where he developed new methods of Xray analysis and he made contributions to crystallography including the dislocation theory.

In 1933, he resigned his position in Germany when Hitler came in power. Within a few months he was invited to take the chair of physical chemistry at the University of Manchester in England. He believed from his experience in science that there was a necessary connection between the premises of a free society and the discovery of scientific truths. In 1938 he formed the Society for the Freedom of Science.

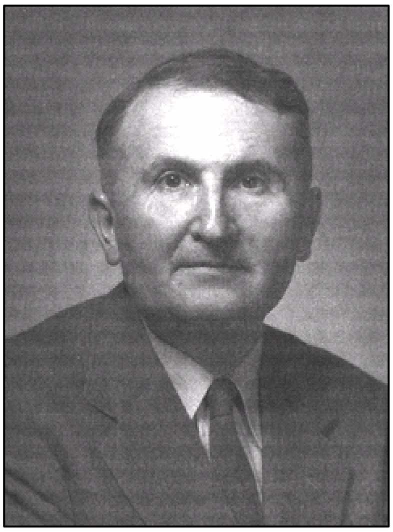
M. Polanyi

**1.3.6. E. Orowan**

Egon Orowan (1902 – 1989) was born in Budapest and received doctorate from Berlin TH on the fracture of mica in 1932. He had difficulty in finding employment and spent the next few years ruminating on his doctoral research, and completed the paper on dislocation.

After working for a short while on the extraction of krypton from the air for the manufacture of light bulbs in Hungary, Orowan moved in 1937 to the University of Birmingham where he worked on the theory of fatigue collaborating with R. Peierls (1907-1955:metal physics).

In 1939, he moved to Cambridge University where W.L.Bragg (1890-1971:X-ray analysis) inspired his interest in X-ray diffraction. During World War II, he worked on problems of munitions production, particularly that of plastic flow during rolling. In 1950, he moved to MIT where, in addition to continuing his metallurgical work, he developed his interests in geological and glaciological deformation and fracture.



E. Orowan

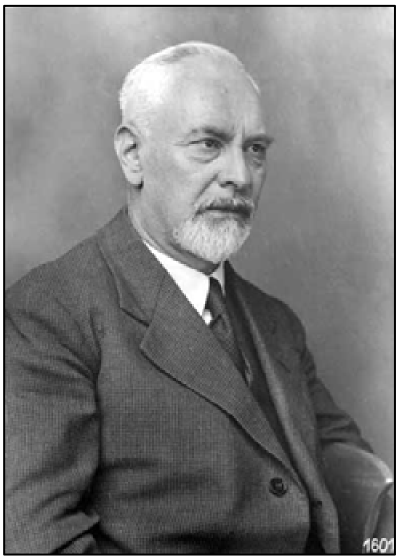
## 1.4. METAL FORMING ANALYSIS

### 1.4.1. L. Prandtl

Ludwig Prandtl ( 1870 – 1953 ) received engineering education at the Munich TH. After graduating, he remained at the school as an assistant of A.Föppl (1854 – 1924: successor of J.Bauschinger), and carried out doctoral work on bending of circular plates. After working in the industry for a while, he was appointed as a professor of industrial mechanics of Hannover TH in 1900. There he proposed membrane analogy of torsion and boundary layer of fluid flow. In 1904 he was invited to the Institute of Mechanics in Göttingen University. Soon he began to study plasticity such as plastic buckling and bending. He was appointed the leader of the laboratory of aerodynamics, and studied wing theorem and other important works of fluid dynamics.

In 1922 Prandtl established the society of applied mathematics and mechanics, "Gesellschaft für Angewandte Mathematik und Mechanik", and led the area of applied mechanics. He is also famous as the teacher of many leaders in mechanics in the 20th century such as Th. von Kármán (California Institute of Technology), S.P. Timoshenko (Stanford University), A.Nádai (Westinghouse Laboratory), W. Prager (Brown University) and others.

L.Prandtl



### 1.4.2. H.Hencky

Heinrich Hencky (1885 – 1951) graduated from Darmstadt TH and began to work in Ukraine as an engineer of a rail-way company in 1913 at the age of 28. Soon the World War I began and the area was occupied by Russian troops, and he was kept in the camp in Ural, where he married a Russian woman.

Although he could not find permanent job after the war in Germany, he got Habilitation (qualification for professorship) from Dresden TH and found a job in Delft Technical University in 1922. He carried out the research of slip-line field theory in Delft, and stayed until 1929.

In 1930 he moved to MIT in the USA, but his scientific approach to engineering was not accepted there because practical technologies were overwhelming, and he resigned MIT only after 2 years. In 1936, Hencky was invited to the Soviet Union by B.G..Galerkin (1871 - 1945: variational method) and carried out research in Moscow University. But in 1938, the relation between the Soviet Union and Germany was worsened and he returned to Germany, and worked in a bus manufacturing company in Mainz.

H.Hencky

### 1.4.3. W. Prager

William Prager (1903 - 1980) was born in Karlsruhe, and studied in Darmstadt TH receiving doctorate in 1926 at the age of 23. From 1929 to 1933 he worked as the acting director of Pramdtl's Applied Mechanics Institute at Göttingen. At the age of 29, he was appointed professor in Karlsruhe TH as youngest professor in Germany, but soon he was dismissed when Hitler came in power. He was invited to Istanbul University, Turkey and acted as a special adviser in education to the government. Prager remained in Istanbul until 1941. The expansion of the World War II made the position of the German refugees insecure, and he accepted the invitation of Brown University in the USA made on the recommendation of A. Einstein.

The Graduate Division of Applied Mathematics of Brown University was created in 1946 with Prager as its first Chairman, a position he held until 1953. By his effort, Brown University became the centre of applied mechanics, especially in the area of plasticity in the 1950s and 60s.

William Prager

### 1.4.4. R. Hill

Rodney Hill (1921 – 2011) was born in Yorkshire, England and read mathematics in Gonville and Caius College, Cambridge, where E.Orowan was teaching. In 1943, amid the World War II, he joined theoretical group of armament led by N.Mott and he was assigned a problem of deep penetration of thick armour by high-velocity shell. This aroused Hill's interest in the field of plasticity. From 1946, he began to work with the group of metal physicist under E.Orowan at the Cavendish Laboratory in Cambridge. He solved various metal forming problems using plasticity theory, and obtained PhD in 1948. In 1949 he was invited to head of new Section of Metal Flow Research Laboratory of British Iron and Steel Association (BISRA).

Hill expanded his Ph.D. thesis and published the book "The Mathematical Theory of Plasticity" in 1950 when he was 29 years old. This book was accepted as a standard of mechanics of plasticity. In 1952, He became the Editor in Chief of a new journal "Journal of Mechanics and Physics of Solids", which was eventually known as the highest level journal in mechanics. In 1953 he applied and was offered the post of a new Chair of Applied Mathematics in Nottingham University, and undertook administrative work on top of the research works of plasticity until his retirement from the university in 1962. Since 1963, Hill moved back to Cambridge and continued research work in solid mechanics.

**1.4.5. E.Siebel**

Erich Siebel (1891 – 1961) received the doctorate from Berlin TH in 1923 at age of 32, on the topic of calculation of load and energy in forging and rolling. After working in a steel industry for a short time, he became a leader of the metal forming division at Kaiser Institute in Dusseldorf (steel), and carried out analysis of rolling and forging. In 1931 he became a professor of Stuttgart TH, and treated almost all areas of metal forming such as deep drawing and wire drawing. Siebel numerically calculated the average pressures for some typical cases of forging, and discussed the way to apply the result to backward extrusion. In the case of compression of cylinder he derived the average contacting pressure as:

$$\bar{p} = Y[1 + \frac{1}{3}\mu\left(\frac{d}{h}\right)].$$

He made the basis of theoretical research of metal forming until retirement in 1957.

E.Siebel

### 1.4.6. H. Kudo

Hideaki Kudo (1924- 2001) graduated from Tokyo Imperial University in 1945 just after the World War II, and started his career at the Institute of Science and Technology in Tokyo University under the guidance of S. Fukui. He developed axi-symmetric analysis as an approximate energy method without knowing that his method was on the line of the upper bound theorem. He was awarded doctoral degree on the thesis of the analysis of forging.

From 1959 to 1960 Kudo stayed in Hannover TH with O. Kienzle and Manchester University with W. Johnson and wrote the papers on the upper bound method and the book.

In 1960 he joined the Government Mechanical Engineering Laboratory in Tokyo as the team leader of cold forging. He worked hard for the promotion of the industrialization of cold forging and published many papers and solved various practical problems.

In 1966 Kudo was appointed to a professorship at Yokohama National University where he held the chair for metal forming until 1989. He carried out fundamental studies of slip-line fields, lubrication, material properties and so on as well as unique forming methods such as tension-aided can extrusion.

Kudo is one of the originators of the Japanese Society for the Technology of Plasticity and was President of JSTP for 1985/6. He also originated the International Conference for Technology of Plasticity (ICTP) and served as the chairman of the first meeting held in Tokyo in 1984.

H.Kudo

# 2. Machines for Metal Forming

## 2.1. MECHANICAL PRESSES

### 2.1.1. Types of drive for mechanical presses

In most mechanical presses, a flywheel is the major source of energy that is applied to the slides by cranks, gears, eccentrics, or linkages during the working part of the stroke. The flywheel runs continuously and is engaged by the clutch only when a press stroke is needed. In some very large mechanical presses the drive motor is directly connected to the press shaft, thus eliminating the need for a flywheel and a clutch. Two basic types of drive, gear and nongeared, are used to transfer the rotational force of the flywheel to the main shaft of the press.

**Nongeared Drive.** In a nongeared drive (also known as a flywheel drive), the flywheel is on the main shaft (Fig. 2.1a), and its speed, in revolutions per minute, controls the slide speed. Usually press speeds with this type of drive are high, ranging from 60 to 1000 strokes per minute. The main shaft can have a crankshaft, as shown in Fig. 2.1a, or an eccentric.

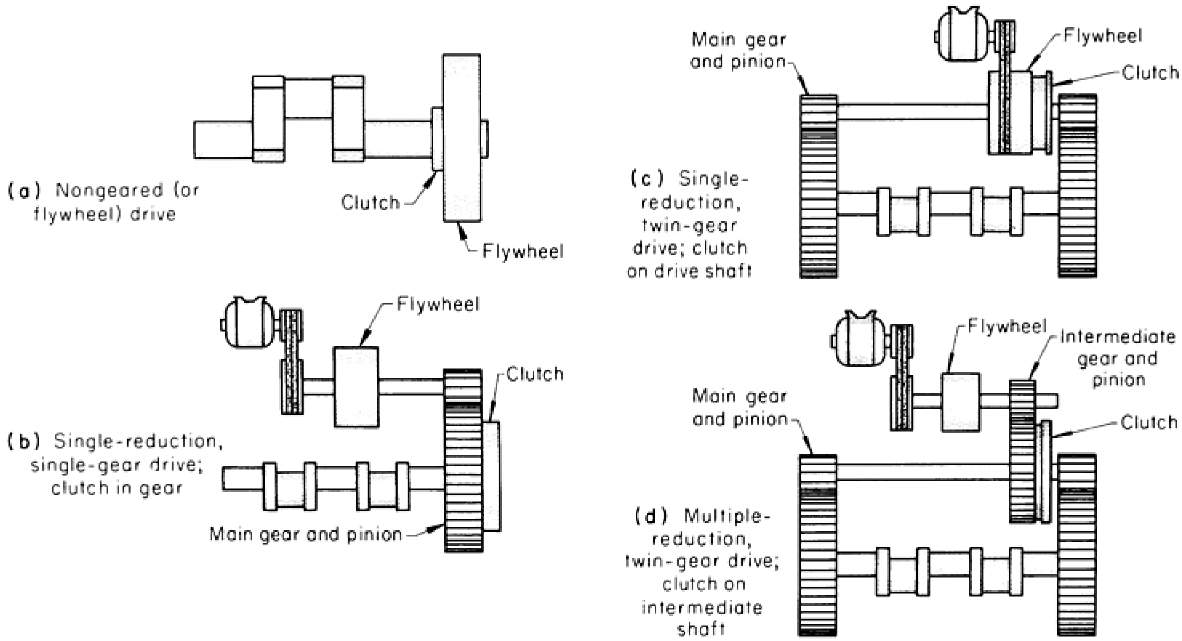



**Fig. 2.1.** Four types of drive and clutch arrangements for mechanical presses.

Energy stored in the flywheel should be sufficient to ensure that the reduction in the speed of the flywheel will be no greater than 10% per press stroke. If the energy in the flywheel is not sufficient to maintain this minimum in speed reduction, a gear-driven press should be used.

**Gear drives** (Fig. 2.1 b, c, and d) have the flywheel on an auxiliary shaft that drives the main shaft through one or more gear reductions. Either single-reduction or multiple-reduction gear drives are used, depending on size and tonnage requirements. In gear-driven presses, there is more flywheel energy available for doing work than there is in the nongeared presses, because the speed of the flywheel is higher than that of the main shaft. The flywheel shaft of a geardriven press often is connected to the main shaft at both ends (Fig. 2.1c), which results in a more efficient drive. A single-reduction gear drive develops speeds of 30 to 100 strokes per minute. Speed for a multiple-reduction twin gear drive (Fig. 2.1d) is usually 10 to 30 strokes per minute, which provides exceptionally steady pressure.

### 2.1.2. Mechanical Forging Presses

All mechanical presses employ flywheel energy, which is transferred to the workpiece by a network of gears, cracks, eccentrics, or levers. Driven by an electric motor and controlled by means of an air clutch, mechanical presses have a full eccentric type of drive shaft that imparts a constant-length stroke to a vertically operating ram (Fig. 2.2). Various mechanisms are used to translate the rotary motion of the eccentric shaft into linear motion to move the ram. The ram carries the top, or moving, die, while the bottom, or stationary, die is clamped to the die seat of the main frame. The ram stroke is shorter than that of a forging hammer or a hydraulic press. Ram speed is greatest at the center of the stroke, but force is greatest at the bottom of the stroke. The capacities of these forging presses are rated on the maximum force they can apply and range from about 2.7 to 142 MN.

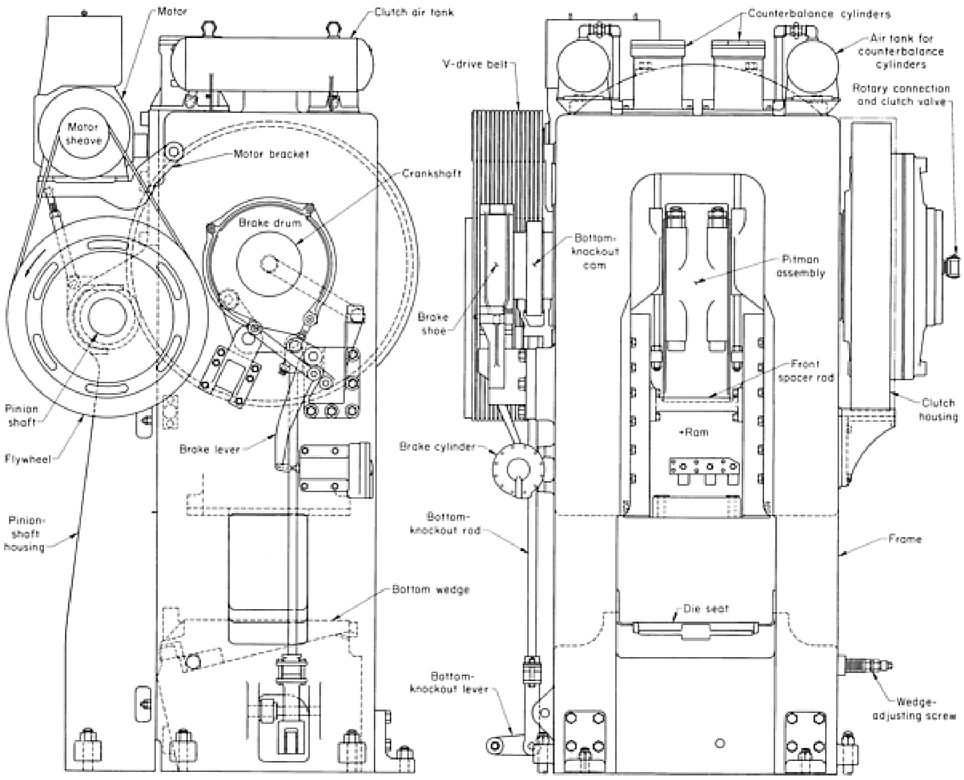



**Fig. 2.2.** Principal components of a mechanical forging press

**Drive Mechanisms**

In most mechanical presses, the rotary motion of the eccentric shaft is translated into linear motion in one of three ways: through a pitman arm, through a pitman arm and wedge, or through a Scotch-yoke mechanism.

### 2.1.3. Pitman arm press drive

**In a pitman arm press drive** (Fig. 2.3), the torque derived from the rotating flywheel is transmitted from the eccentric shaft to the ram through a pitman arm (connecting rod). Presses using single- or twin-pitman design are available. Twinpitman design limits the tilting or eccentric action resulting from off-center loading on wide presses. The shut height of the press can be adjusted mechanically or hydraulically through wedges. Mechanical presses with this type of drive are capable of forging parts that are located in an off-center position.

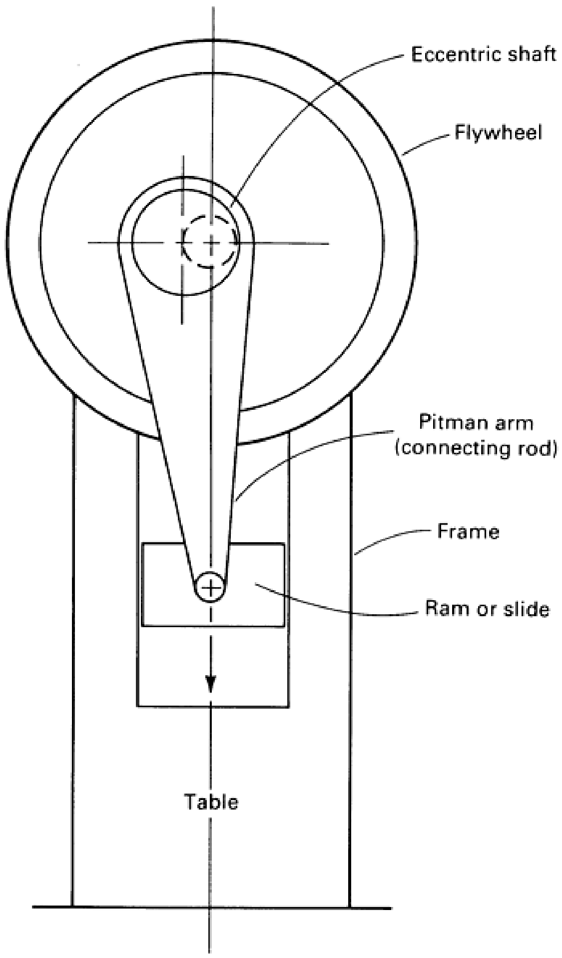



**Fig. 2.3.** Principle of operation of a mechanical press driven by a pitman arm (connecting rod)

### 2.1.4. A wedge drive

**A wedge drive** (Fig. 2.4) consists of a massive wedge sloped upward at an angle of 30° toward the pitman, an adjustable pitman arm, and an eccentric driveshaft. The torque form the rotating flywheel is transmitted into horizontal motion through the pitman arm and the wedge. As the wedge is forced between the frame and the ram, the ram is pushed downward; this provides the force required to forge the part. The amount of wedge penetration between the ram and frame determines the shut height of the ram. The shut height can be adjusted by rotating the eccentric bushing on the eccentric shaft by means of a worm gear. A ratchet mechanism prevents the adjustment from changing during press operation.

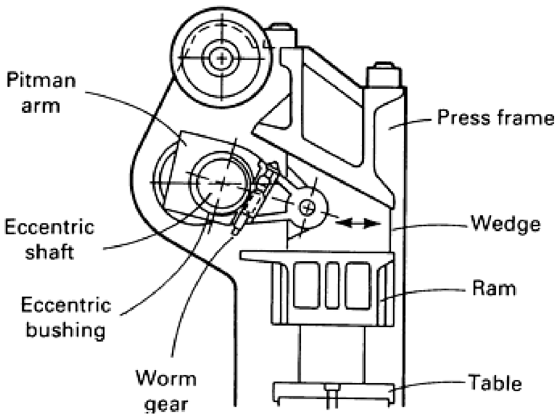



**Fig. 2.4.** Principle of operation of a wedge-driven press.

Wedge drives transmit the forging force more uniformly over the entire die surface than pitman arm drives. Wedge drives also reduce ram tilting due to off-center loading. Increases in forging accuracies during on-center and off-center loading conditions and the ability to adjust the shut height are the main advantages of wedge-driven mechanical presses. A disadvantage is the relatively long contact time between the die and the forged part.

### 2.1.5. The scotch-yoke drive

**The Scotch-yoke drive** (Fig. 2.5) contains an eccentric block that wraps around the eccentric shaft and is contained within the ram. As the shaft rotates, the eccentric block moves in both horizontal and vertical directions, while the ram is actuated by the eccentric block only in a vertical direction. The shut height of the ram can be adjusted mechanically or hydropneumatically through wedges.

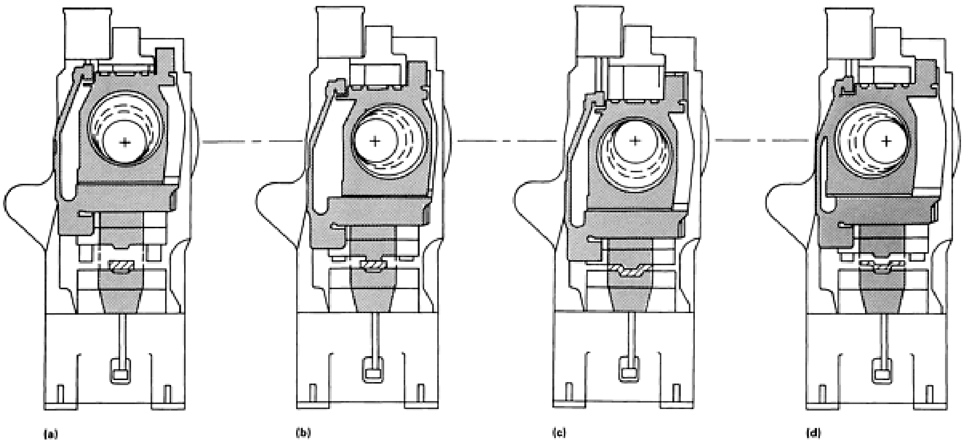



**Fig. 2.5.** Principle of operation of mechanical press with a Scotch yoke drive. (a) The ram is at the top of the stroke; the Scotch yoke is centered. (b) Scotch yoke is in the extreme forward position midway through the downward stroke. (c) At bottom dead center, the Scotch yoke is in the center of the ram. (d) Midway through the upward stroke, the Scotch yoke is in the extreme rear position.

This press design provides more rigid guidance for the ram, which results in more accurate forgings. Forging of parts off center is also possible with this type of drive. Because the drive system is more compact than the pitman arm drive, the press has a shorter overall height.

### 2.1.6. Straight-side presses

**Straight-side presses** have a frame made up of a base, or bed; two columns; and a top member, or crown. In most straight-side presses, steel tie rods hold the base and crown against the columns. Straight-side presses have crankshaft, eccentric-shaft, or eccentric-gear drives. A single-action straight-side press is shown in Fig. 2.6. The slide in this illustration is equipped with air counterbalances to assist the drive in lifting the weight of the slide and the upper die to the top of the stroke. Counterbalance cylinders provide a smooth press operation and easy slide adjustment. Die cushions are used in the bed for blank-holding and for ejection of the work.

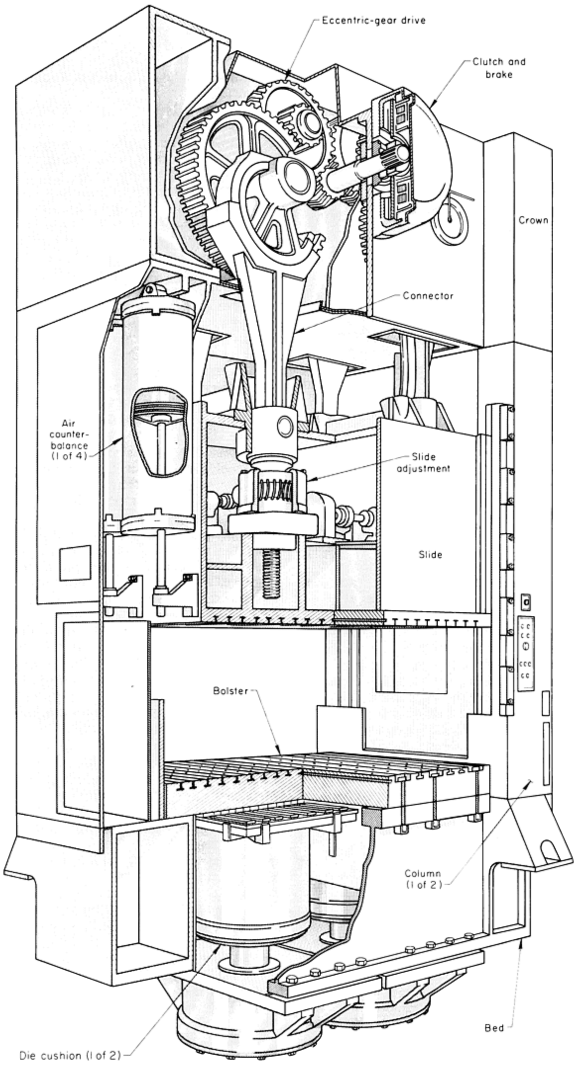



**Fig. 2.6.** Principal components of a single-action straight-side mechanical press. The press shown has a large bed, four-point suspension, and an eccentric drive with counterbalance cylinders. Slide adjustment is motorized.

The straight-side design permits the use of an endless variety of bed and slide sizes. Presses range from 180 kN (20 tonf) capacity and a bed of 510 × 380 mm (20 × 15 in.), to 36 MN (4000 tonf) capacity with a bed as large as 915 mm (360 in.) left-to-right by 455 mm (180 in.) front-to-back. The size and shape of the slide usually determine the number of points of suspension, or connections between the main shaft and the slide, that are needed. The straight-side design also can provide high pressures with minimum deflection. A straight-side press deflects less under off-center loads than does a gap-frame press.

### 2.1.7. Die Cushions

**Die cushions**, often referred to as pressure pads, are used to apply pressure to flat blanks for drawing operations. They also serve as knock-out or ejection devices to remove stampings from the dies. Single-action presses do not have an integral means for blankholding and require the use of cushions or other means of applying uniform pressure to the blanks for drawing operations, except for shallow draws in thick stock. The most common means of pressure control for drawing operations on single-action presses are pneumatic and hydropneumatic die cushions. Figure 2.7a shows a single-action press set up for use with a die cushion.

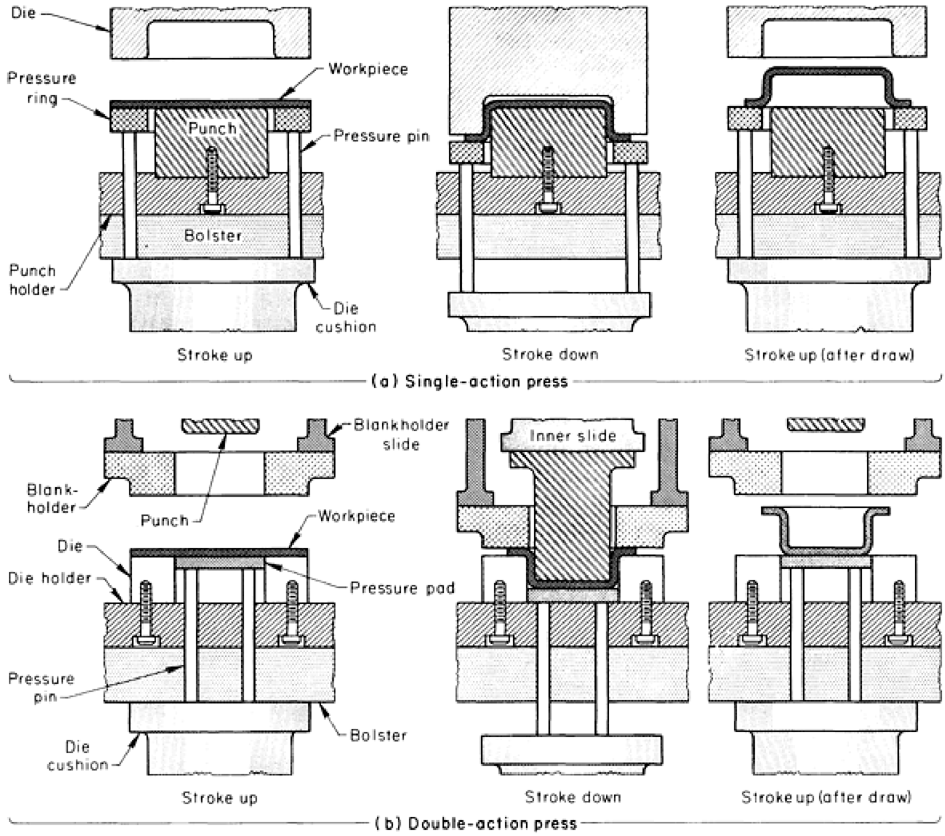



**Fig. 2.7.** Setups incorporating die cushions in single-action and double-action presses.

Double- and triple-action presses feature integral blankholders and do not require cushions for drawing operations. Cushions are sometimes employed on double-action presses, however (Fig. 2.7b), for ejection of triple-action draws, for keeping the bottoms of the stampings flat or ensuring that they hold their shapes, or for preventing slippage while drawing. For such applications, the cushions must be equipped with locking devices to hold the cushions at the bottom of stroke for a predetermined length of the return stroke of the press slide. Most die cushions are located in the press beds, but there are applications that require installation within or on the press slides. In either case, the functions are similar, and the operations are the same. Consideration must be given to the press capacity at the point at which the draw is to begin, because the force and energy required to depress the cushion is added to that required to draw the stamping. As a result, the force and energy needed for a high-capacity cushion may not leave enough for the operation to be performed.

## 2.2. PRESS-BRAKE FORMING

### 2.2.1. Press Brakes

The primary advantages of press brakes are versatility, the ease and speed with which they can be changed over to a new setup, and low tooling costs. A press brake is basically a slow-speed punch press that has a long, relatively narrow bed and a ram mounted between end housings (Fig. 2.8). Rams are actuated mechanically or hydraulically.

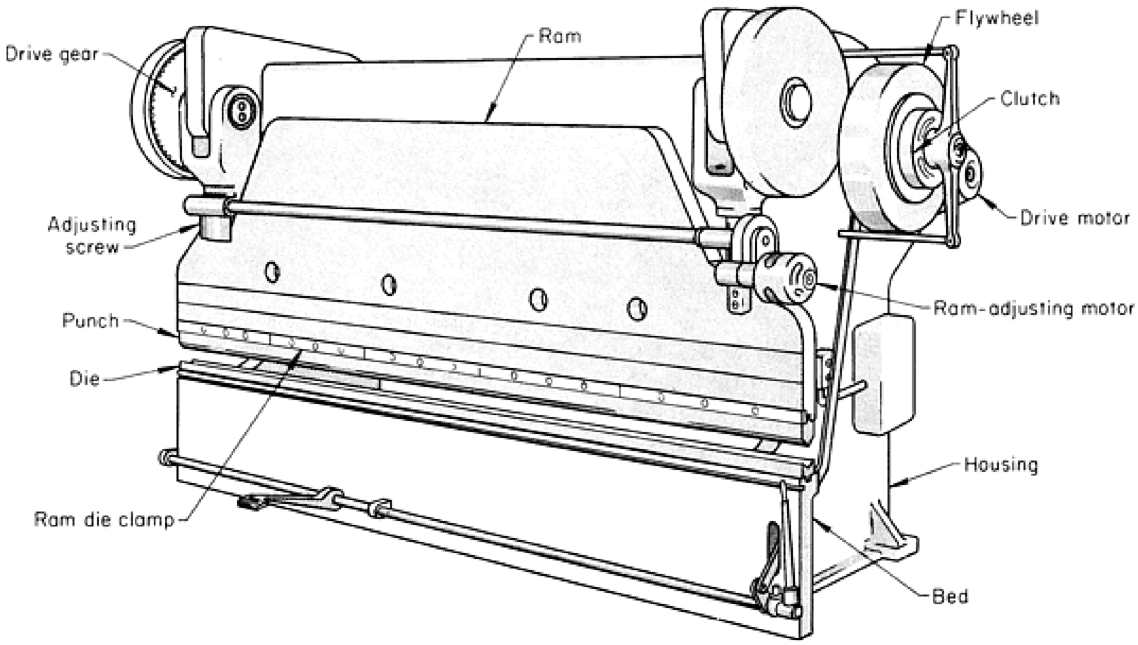



**Fig. 2.8.** Principal components of a mechanical press brake.

**Mechanical Press Brakes.** The ram of a mechanical press brake is actuated by a crank or an eccentric through a gear train in which there is a clutch and a flywheel.

**Hydraulic Press Brakes.** The ram of a hydraulic press brake is actuated by two double-acting cylinders, one at each end of the ram. Force supplied by the hydraulic mechanism will not exceed the press rating; therefore, it is almost impossible to overload a hydraulic press brake. Therefore, frames can be lighter and less costly than those for mechanical press brakes, which are subject to overloading.

## 2.3. HYDRAULIC PRESSES

### 2.3.1. Hydraulic Presses for Sheet Forming

Hydrostatic pressure against one or more pistons provides the power for a hydraulic press. Most hydraulic presses have a variable-volume, variable-pressure, concentric-piston pump to provide them with a fast slide opening and closing speed. It also provides a slow working speed at high forming pressure. The principal components of a typical hydraulic press are shown in Fig. 2.9. A bolster plate is attached to the bed to support the dies and to guide the pressure pins between the die cushion and the pressure pad.

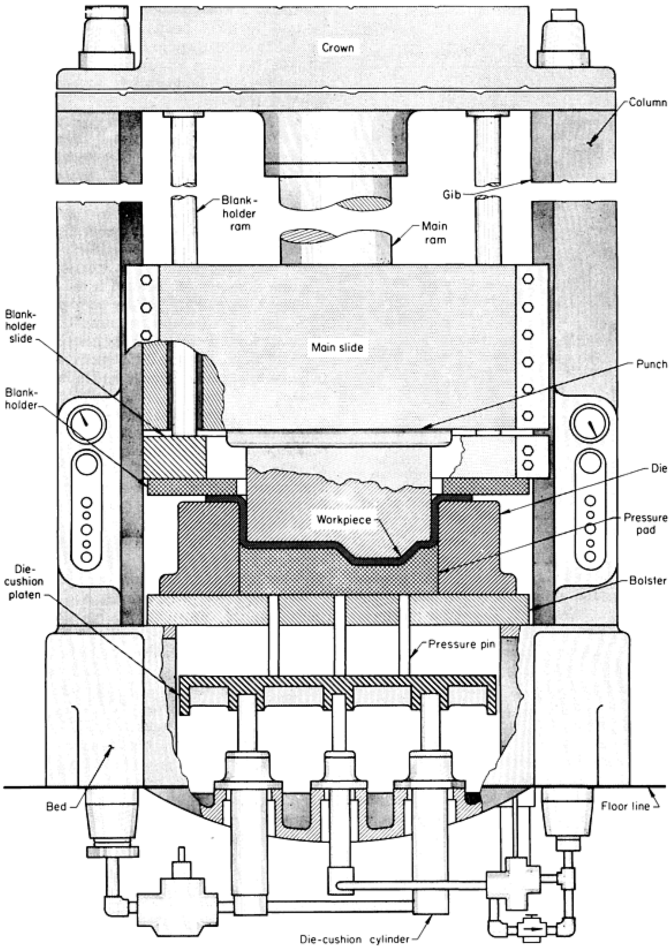



**Fig. 2.9.** Principal components of a double-action hydraulic press with a die cushion.

The capacity of a hydraulic press depends on the diameter of the hydraulic pistons and on the rated maximum hydraulic pressure, the latter being a function of the pump pressure and related mechanisms.

Because of their construction, hydraulic presses can be custom designed at a relatively low cost. They can be designed with a number of slides and motions, or separate hydraulic circuits can be used for various independent actions. In addition, side action can be provided within the frame of the press by means of separate cylinders. Such side action in a mechanical press is usually provided by cams and is complex and expensive. Most hydraulic presses are straight-side models, but small, fast, gap-type presses designed to compete with mechanical open-back inclinable presses have been developed.

### 2.3.2. Hydraulic Presses for Forging

**Hydraulic presses** are used for both open- and closed-die forging. The ram of a hydraulic press is driven by hydraulic cylinders and pistons, which are part of a high-pressure hydraulic or hydro-pneumatic system. After a rapid approach speed, the ram (with upper die attached) moves at a slow speed while exerting a squeezing force on the work metal. Pressing speeds can be accurately controlled to permit control of metal-flow velocities; this is particularly advantageous in producing close-tolerance forgings. The principal components of a hydraulic press are shown in Fig. 2.10.

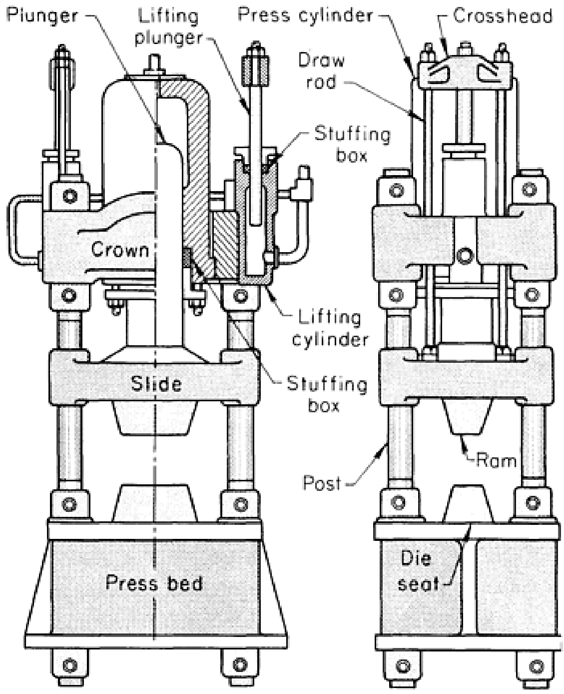



**Fig. 2.10.** Principal components of a four-post hydraulic press for closed-die forging

Some presses are equipped with a hydraulic control circuit designed specifically for precision forging. With this circuit, it is possible to obtain a rapid advance stroke, followed by preselected first and second pressing speeds. If necessary, the maximum force of the press can be used at the end of the second pressing stroke with no limits on dwell time. The same circuit also provides for a slow pullout speed and can actuate ejectors and strippers at selected intervals during the return stroke.

### 2.3.3. Multiple-ram presses

Hollow, flashless forgings that are suitable for use in the manufacture of valve bodies, hydraulic cylinders, seamless tubes, and a variety of pressure vessels can be produced in a hydraulic press with multiple rams. The rams converge on the workpiece in vertical and horizontal planes, alternately or in combination, and fill the die by displacement of metal outward from a central cavity developed by one or more of the punches. Figure 2.11 illustrates the multiple-ram principle, with central displacement of metal proceeding from the vertical and horizontal planes.

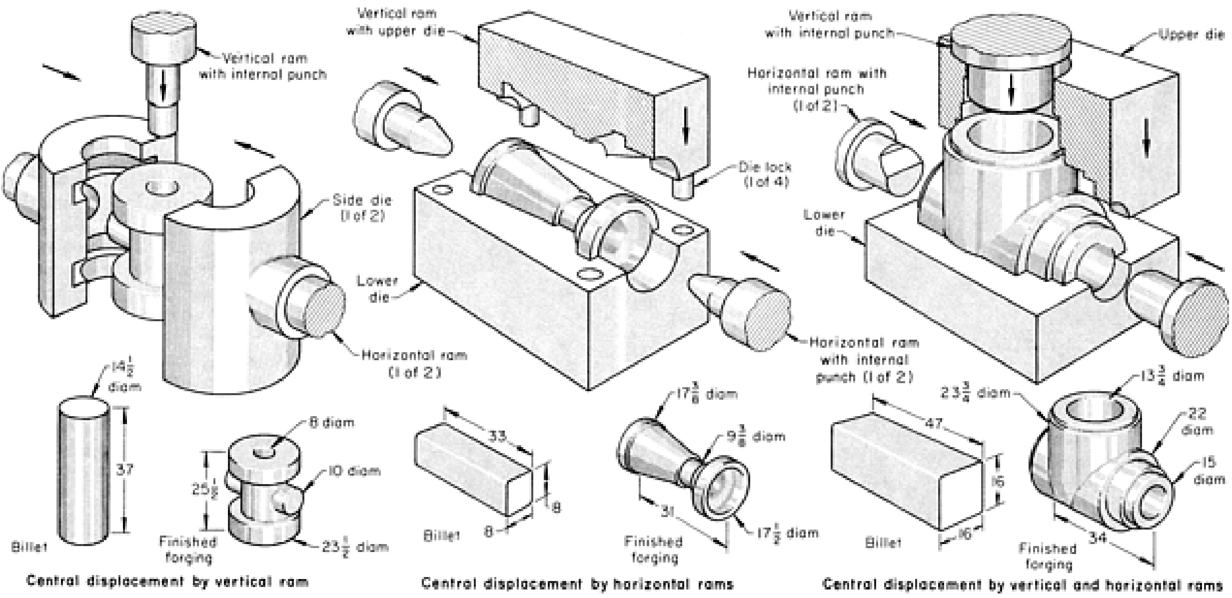



**Fig. 2.11.** Examples of multiple-ram forgings. Displacement of metal can take place from vertical, horizontal, and combined vertical and horizontal planes. Dimensions given in inches

Piercing holes in a forging at an angle to the normal direction of forging force can result in considerable material savings, as well as savings in the machining time required to generate such holes. In addition to having the forging versatility provided by multiple rams, these presses can be used for forward or reverse extrusion. Elimination of flash at the parting line is a major factor in decreasing stress-corrosion cracking in forging alloys susceptible to this type of failure, and the multidirectional hot working that is characteristic of processing in these presses decreases the adverse directional effects on mechanical properties.

## 2.4. HAMMERS

### 2.4.1. Hammers for open die forging

Gravity-drop hammers and power-drop hammers are comparable to a single-action press. However, they can be used to perform the work of a press equipped with double-action dies through the use of rubber pads, beads in the die surfaces, draw rings, and other auxiliary equipment. Because they can be controlled more accurately and because their blows can be varied in intensity and speed, power-drop hammers, particularly the air-actuated types, have virtually replaced gravity-drop hammers. A typical air-drop hammer, equipped for drop hammer forming, is shown in Fig. 2.12.

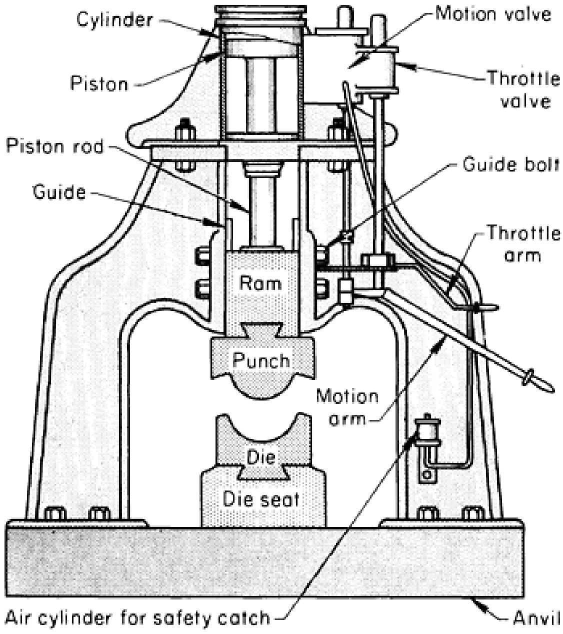



**Fig. 2.12.** Schematic of an air-actuated power-drop hammer equipped for drop hammer forming.

Power-drop hammers are rated from 4.5 to 155 kN (10M to 35,000 lbf), representing energies from 15 to 575 U (11,000 to 425,000 ft · lb). Air-drop hammers range in size (ram area) from 762 by 610 mm (30 by 24 in.) to 3.05 by 3.05 m (120 by 120 in.) with impact energies ranging from 8.9 to 134 kJ (6600 to 99,000 ft · lbf). Planishing hammers are used to supplement drop hammer forming. These are fast-operating air-driven or motor-driven machines that are generally used for low-production operations to form dual-curvature surfaces. They are also used to planish welds and to smooth out wrinkles or other imperfections in drawn or drop hammer formed parts.

**2.4.2. Power-Drop Hammers for Closed Die Forging**

In a power-drop hammer, the ram is accelerated during the downstroke by air, steam, or hydraulic pressure. The components of a steam- or air-actuated power-drop hammer are shown in Fig. 2.13. This equipment is used almost exclusively for closed-die (impression-die) forging.

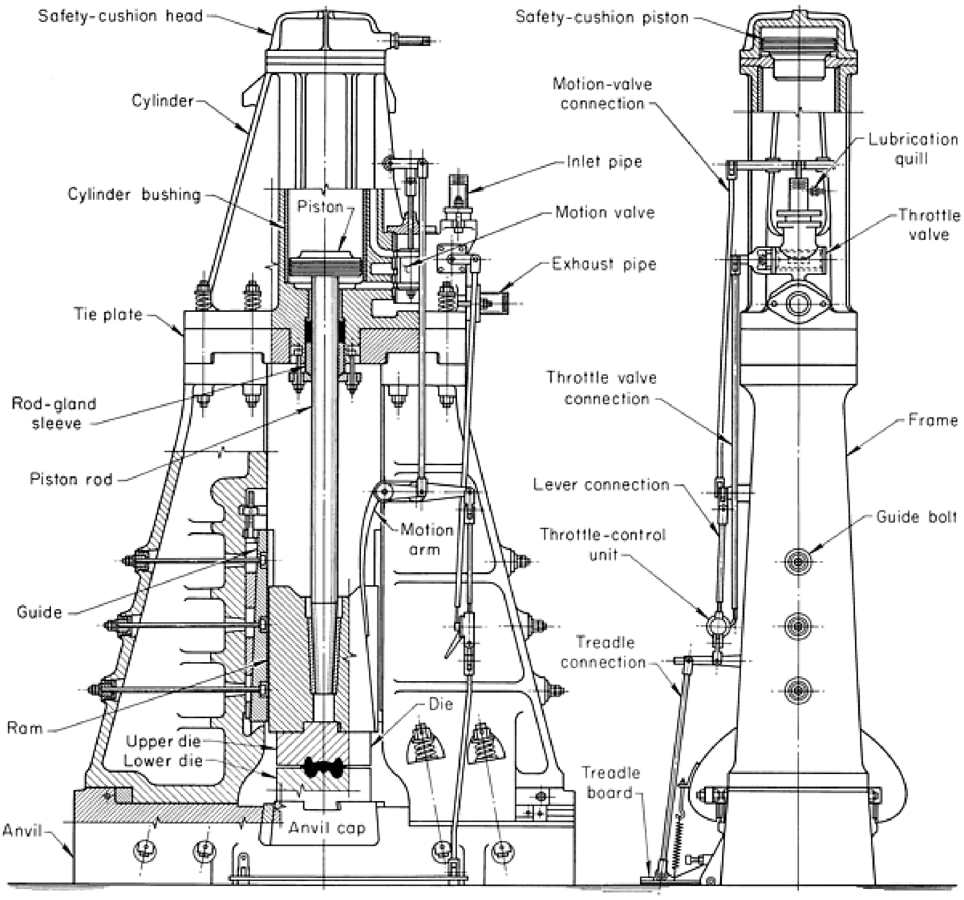



**Fig. 2.13.** Principal components of a power-drop hammer with foot control to regulate the force of the blow

The steam- or air-powered drop hammer is the most powerful machine in general use for the production of forgings by impact pressure. In a power-drop hammer, a heavy anvil block supports two frame members that accurately guide a vertically moving ram; the frame also supports a cylinder that, through a piston and piston rod, drives the ram. In its lower face, the ram carries an upper die, which contains one part of the impression that shapes the forging. The lower die, which contains the remainder of the impression, is keyed into an anvil cap that is firmly wedged in place on the anvil. The motion of the piston is controlled by a valve, which admits steam, air, or hydraulic oil to the upper or lower side of the piston. The valve, in turn, is usually controlled electronically. Most modern power-drop hammers are equipped with programmable electronic blow control that permits adjustment of the intensity of each individual blow.

## 2.5. Screw Presses

**Screw presses** are energy-restricted machines, and they use energy stored in a flywheel to provide the force for forging. The rotating energy of inertia of the flywheel is converted to linear motion by a threaded screw attached to the flywheel on one end and to the ram on the other end. Screw presses are widely used in Europe for job-shop hardware forging, forging of brass and aluminium parts, precision forging of turbine and compressor blades, hand tools, and gear like parts. Recently, screw presses have also been introduced in North America for a wide range of applications, notably, for forging steam turbine and jet engine compressor blades and diesel engine crankshafts. The screw press uses a friction, gear, electric, or hydraulic drive to accelerate the flywheel and the screw assembly, and it converts the angular kinetic energy into the linear energy of the slide or ram. Figure 2.14 shows two basic designs of screw presses.

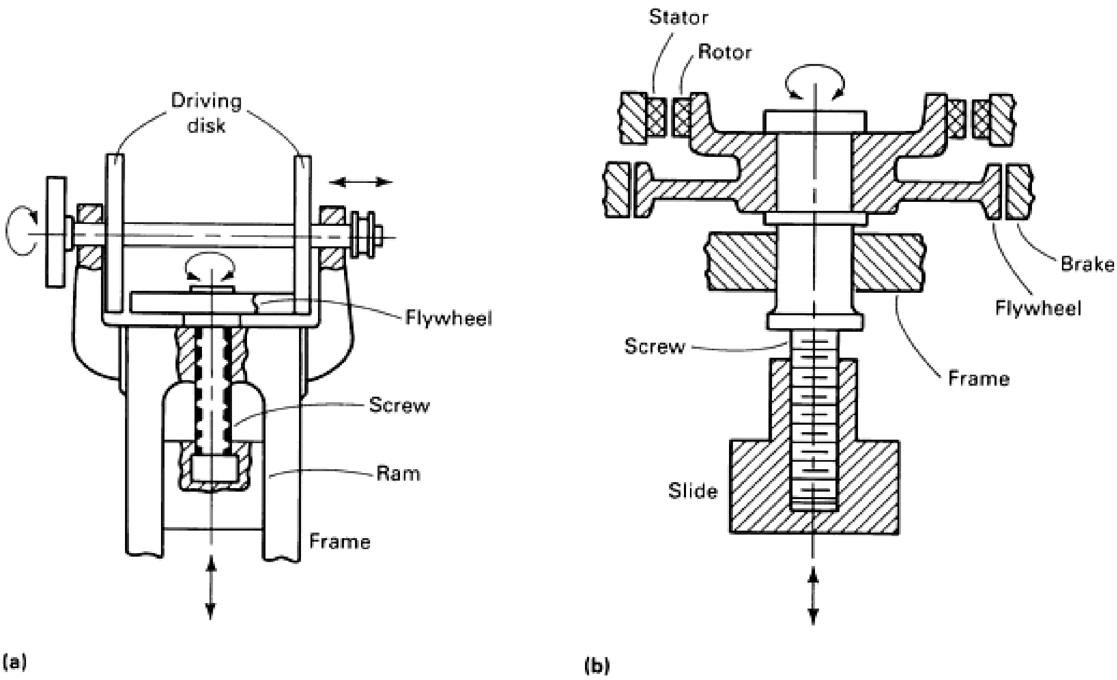



**Fig. 2.14.** Two common types of screw press drives. (a) Friction drive. (b) Direct electric drive

**Drive Systems**

**In the friction drive press** (Fig. 2.14a), two large energy-storing driving disks are mounted on a horizontal shaft and rotated continuously by an electric motor. For a downstroke, one of the driving disks is pressed against the flywheel by a servomotor. The flywheel, which is connected to the screw either positively or by a friction-slip clutch, is accelerated by this driving disk through friction. The flywheel energy and the ram speed continue to increase until the ram hits the workpiece. Thus, the load necessary for forming is built up and transmitted through the slide, the screw, and the bed to the press frame. The flywheel, the screw, and the slide stop when the entire energy in the flywheel is used in deforming theworkpiece and elastically deflecting the press. At this moment, the servomotor activates the horizontal shaft and presses the upstroke-driving disk wheel against the flywheel. Thus, the flywheel and the screw are accelerated in the reverse direction, and the slide is lifted to its top position.

**In the direct-electric-drive press** (Fig. 2.14b), a reversible electric motor is built directly on the screw and on the frame, above the flywheel. The screw is threaded into the ram or slide and does not move vertically. To reverse the direction of flywheel rotation, the electric motor is reversed after each downstroke and upstroke.

## 2.6. SPECIAL MACHINES

### 2.6.1. Machines for Power Spinning

Most power spinning is done in machines specially built for the purpose. The significant components of such a machine are shown in Fig. 2.15. Although Fig. 2.15 illustrates the power spinning of a conical shape, similar machines are used for the spinning of tubes.

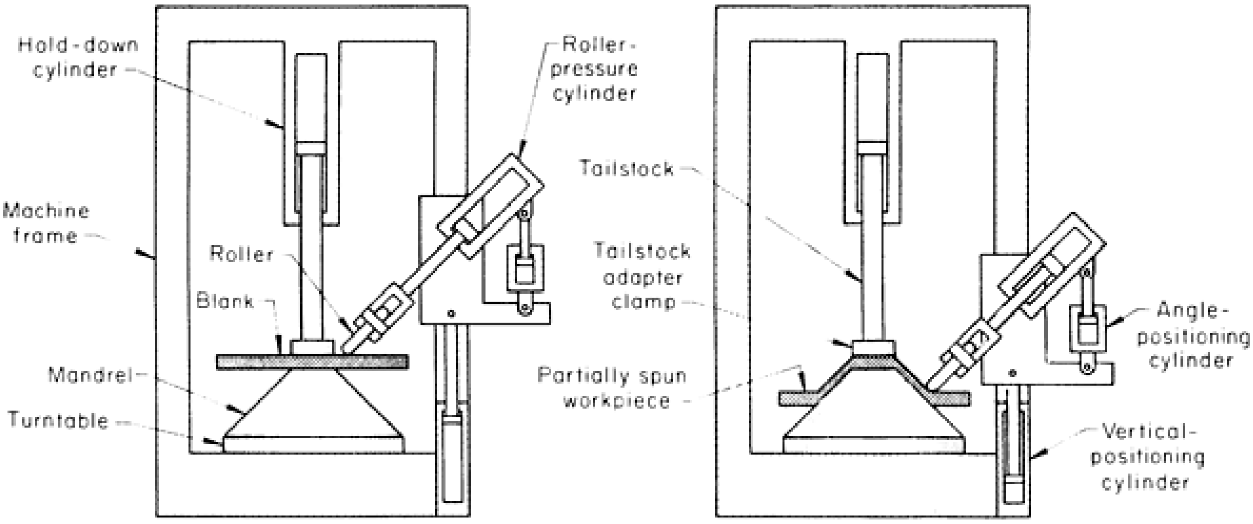



**Fig. 2.15.** Schematic of power spinning in a vertical machine.

Machines for power spinning are usually described by specifying the diameter and length (in inches) of the largest workpiece that can be spun and the amount of force that can be applied to the work. It is also common practice to specify that the machine can spin a given thickness of metal at a 50% reduction in thickness in one pass. The capacity of spinning machines ranges from 455 × 380 mm (18 × 15 in.) at 18 kN (4000 lbf) to machines capable of spinning workpieces as large as 6 m (240 in.) in diameter × 6 m (240 in.) long. Force on the work can be as great as 3.5 MN (800,000 lbf). Machines have been built that spin steel 140 mm (5 in.) thick.

### 2.6.2. Closed-die axial rolling

**Closed-die axial rolling** combines the elements of ring rolling with the elements of closed-die forging. Closed-die axial rolling relies on less than full contact area between the tool and the workpiece (Fig. 2.16) and therefore can produce circular forgings using 90 to 95% less force than would be required in closed-die forging.

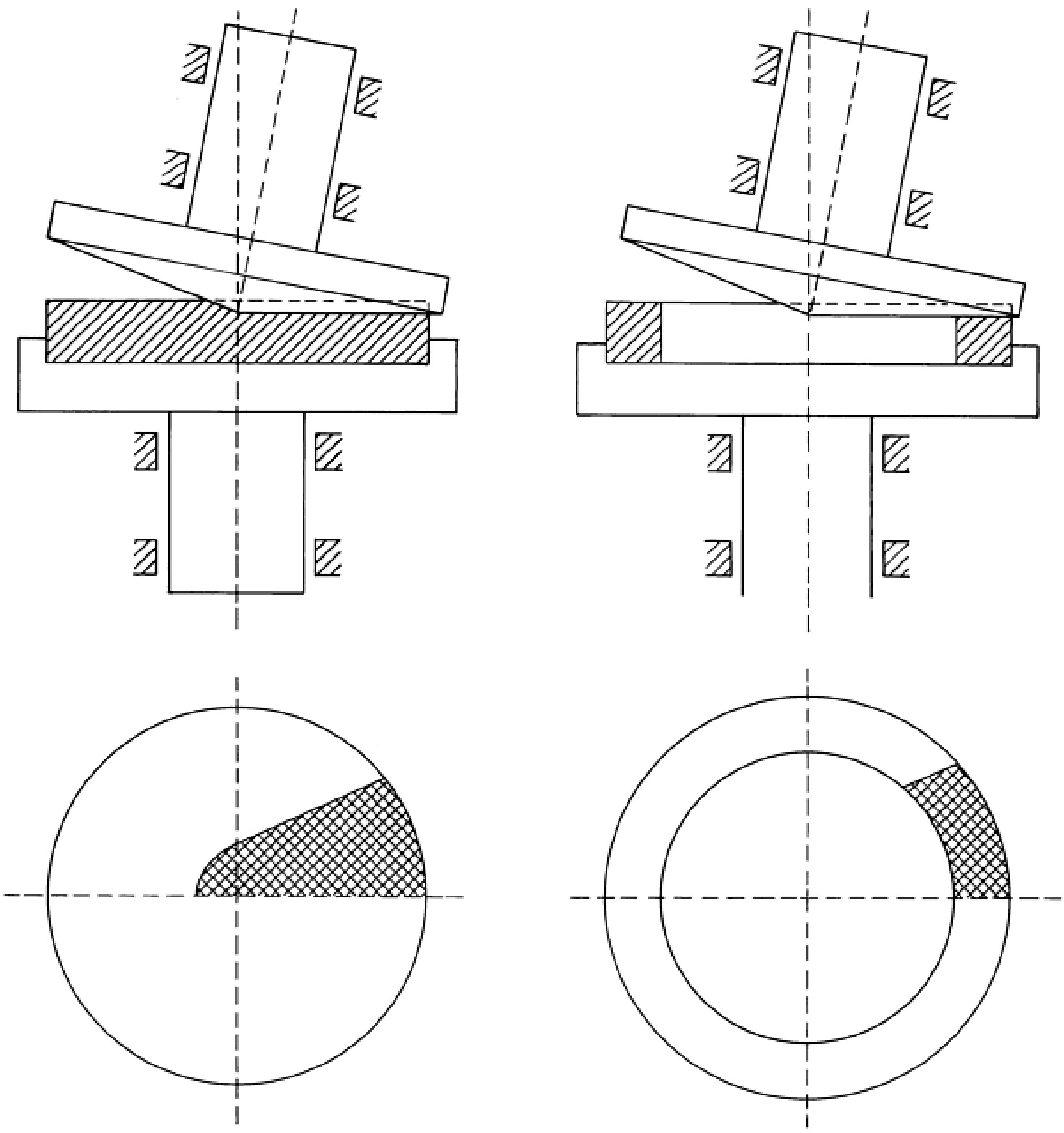


**Fig. 2.16.** Operating principle of the axial closed-die rolling process.

In closed-die axial rolling, the lower tool rotates about its vertical axis, typically at 30 to 250 rpm, and contains the workpiece. The upper tool, its axis inclined at some 7° to that of the lower tool, applies the rolling force. Feed rates in the range of 20 to 300 mm/min (0.75 to 12 in./min) are employed. The direction of tool movement is vertically downward. The conical shape of the upper tool, which would generate a parabolic contact area in the absence of tool rotation, is rotated by the bottom tool, through the workpiece. A semiparabolic contact area results. The starting material may be in the form of a solid block or a prerolled ring. Products can be solid disk-type forgings or annular ring-type components and can be complexly contoured cross sections. Production rates to 120 pieces per hour are possible.

**2.6.3. Flexible Forming**

Reducing the number of stamping dies is another way of lowering part cost. For example, advanced flexible punch-and-die methods based on multipoint methods have been developed in China. Different modes of multipoint forming are shown in Fig. 2.17. In such processes, several hydraulic cylinders work against each other to shape a detail. Early try-outs of the process gave rise to poor surface finish, which was ameliorated to some extent by the use of an intermediate sheet.

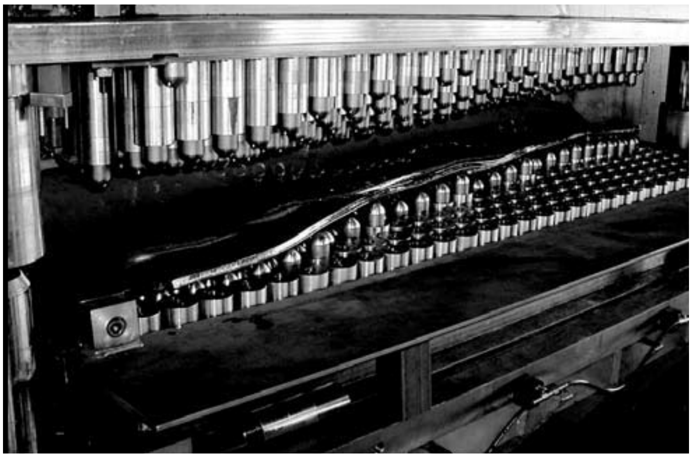


Fig. 2.17.Flexible multipoint forming of 16 mm (0.63 in.) stainless steel sheet

### 2.6.4. Dieless NC Forming

Dieless NC forming is a numerically controlled incremental-forming process developed in Japan that can cold form various materials into complex shapes. The method allows forming without large and expensive dies, using only a simple support tool under the formed piece. This makes the method very cost effective. The technique was developed to meet the needs of the automotive industry as an alternative manufacturing method for small production lot sizes and rapid prototyping.

**Principle of Operation**

In dieless NC the blank is clamped to a square blankholder ("work holder") such that there is no draw-in from the binders. The so-called Z-tool moves in the Z (vertical) and Y directions; the work holder is counterbalanced to the vertical movement of the tool and is translated in the vertical direction according to the descent of the Z-tool and along the X and Y directions. The X and Y plane movements are synchronized with the tool motion to produce the desired form on the sheet (Fig. 2.18). The moving Z-tool slides over the surface of the blank and presses it into the desired form via stretching and bending. Forming starts on the top of the piece, under which the support tool is placed. The tool path and the vertical pitch are defined by special conversion software based on the CAD model of the product (Fig. 2.19).

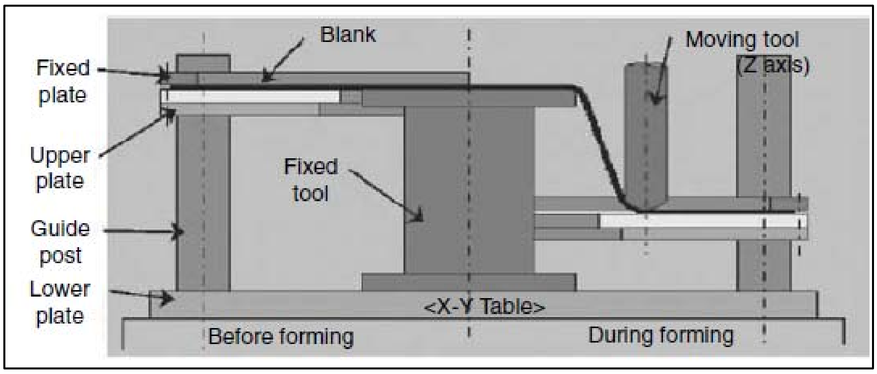


Fig. 2.18. Principle of dieless NC forming.


Fig. 2.19. Dieless NC forming process

### 2.6.5. Laser forming

One example of flexible manufacturing and associated equipment is laser forming (Fig. 2.20). A CO2-laser can be used both to cut the sheet material and to form simple geometries. The heat induced by the laser beam bends the sheet to the calculated geometry. Metals with low thermal conductivity, for example, stainless steels, are more easily deformed. Both thin and thick gages can be formed. The method was originally used for tube bending in the shipbuilding industry. Principal recent developments in this area include models to predict the heating passes needed to produce the desired formed geometry. Laser optics to form circular and double-curved shapes has also been developed recently. Another process similar to laser forming, in which heat is used to generate internal stresses in the material and thus cause the sheet to bend, is plasma jet forming.

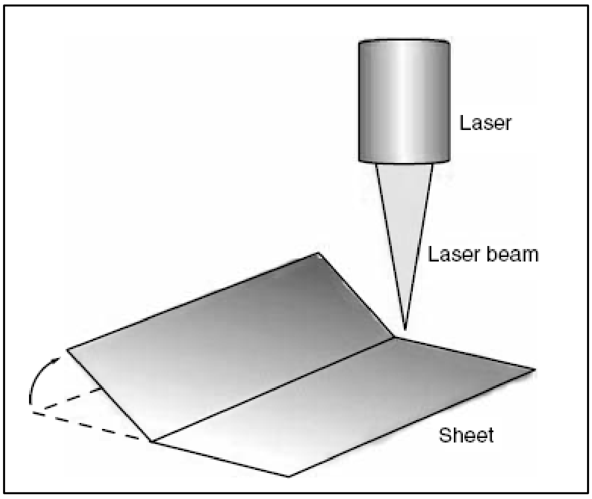



Fig. 2.20. Bending of sheet via laser forming

# 3. Technologies of Metal Forming

## 3.1. OPEN DIE FORGING

### 3.1.1. Handling device for open-die forging

**Porter Bars.** Another handling device is the porter bar. It has a hollow end that is shaped to fit the sinkhead of the billet being forged or some portion of the workpiece. The load, represented by the workpiece and porter bar, is balanced on the sling at the center of gravity of the combined load. The sling is occasionally moved to preserve the balance as the dimensions of the forging change. Figure 3.1 shows a porter bar and a sling used for handling a large forging.

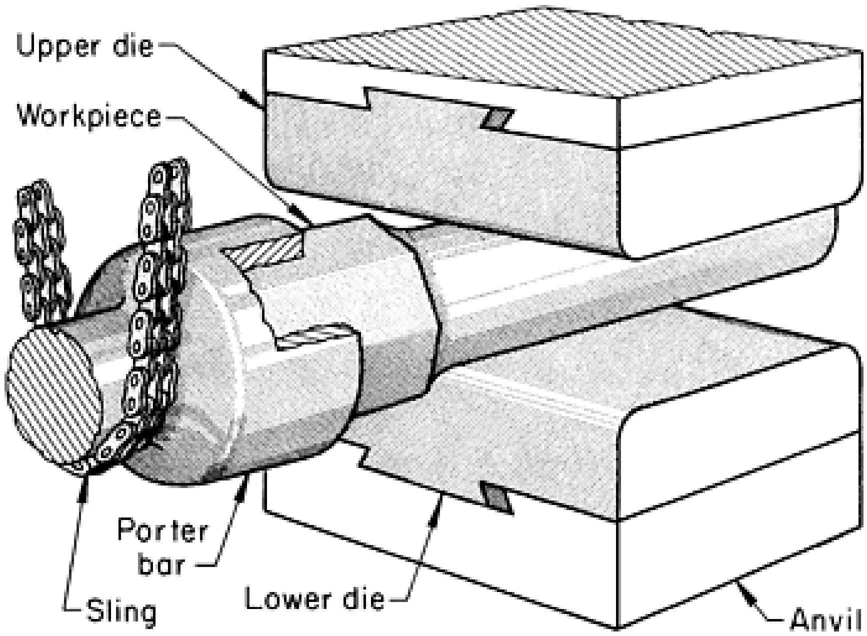



**Fig. 3.1.** Handling a forging by means of a porter bar and a sling

### 3.1.2. Forging a ring

**Auxiliary Tools**

Mandrels, saddle supports, sizing blocks (spacers), ring tools, bolsters, fullers, punches, drifts (expansion tools), and a wide variety of special tools (for producing shapes) are used as auxiliary tools in forging production. Because most auxiliary tools are exposed to heat, they are usually made from the same steels as the dies.

**Saddle Supports.** An open-die forging can be made with an upper die that is flat, while the lower die utilizes another type of tool. Two or more hammers or presses and die setups are often needed to complete a shape (or operations are done at different times in the same hammer or press by changing the tooling). For example, large rings are made by upsetting the stock between two flat dies, punching out the center, and then saddle forging. As shown in Fig. 3.2, the lower die is replaced by a saddle arrangement that supports a mandrel inserted through the hollow workpiece.

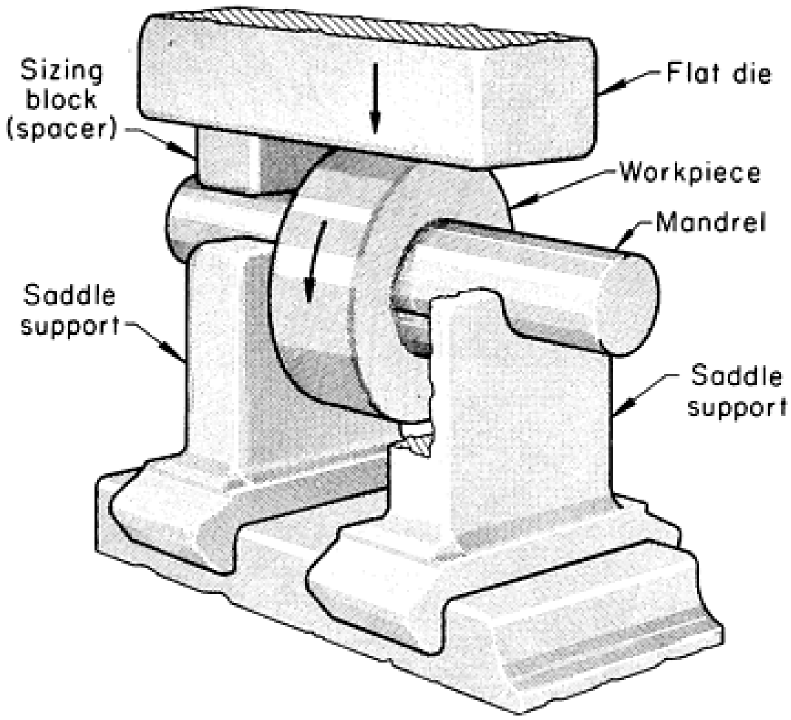



**Fig. 3.2.** Setup for saddle forging a ring

**Sizing Blocks.** A sizing block can be used between the mandrel and the ram to prevent the cross section of the workpiece from being forged too thin. Most state-of-the-art presses have automatic sizing or thickness controls.

### 3.1.3. Ring Tools

A tonghold can be retained on a forging so that the forging can be more easily handled after upsetting, as shown in Fig. 3.3. A ring tool with a center opening is placed on the workpiece. During the upsetting, the hot work metal at the ring tool opening is protected from being upset, and it is back extruded to a tonghold with a length equal to the thickness of the ring tool. Alternatively, the tonghold can be forged on one end of the workpiece prior to upsetting; a hole in the lower die protects the tonghold during the upsetting operation.

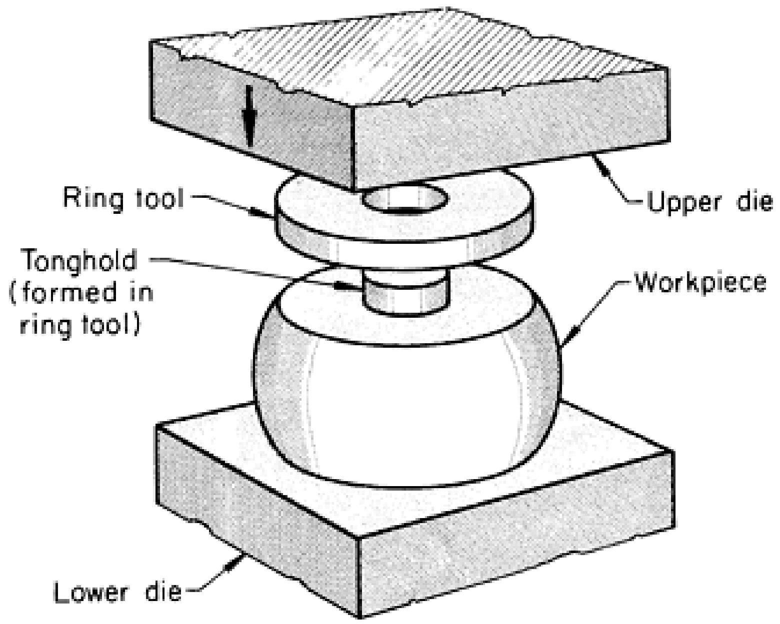



**Fig. 3.3.** Setup showing use of a ring tool for forming and retaining a tonghold in the workpiece during upsetting

**3.1.4. Forging a 170-kg (375-lb) Solid Cylinder in Flat Dies**

A cylinder, 241 mm (9 12in.) in diameter by 470 mm (18 12in.) in length, was forged in flat dies from 305 × 305 × 254 mm (12 × 12 × 10 in.) stock in four operations without reheating the billet (Fig. 3.4). The following sequence of operations was used.

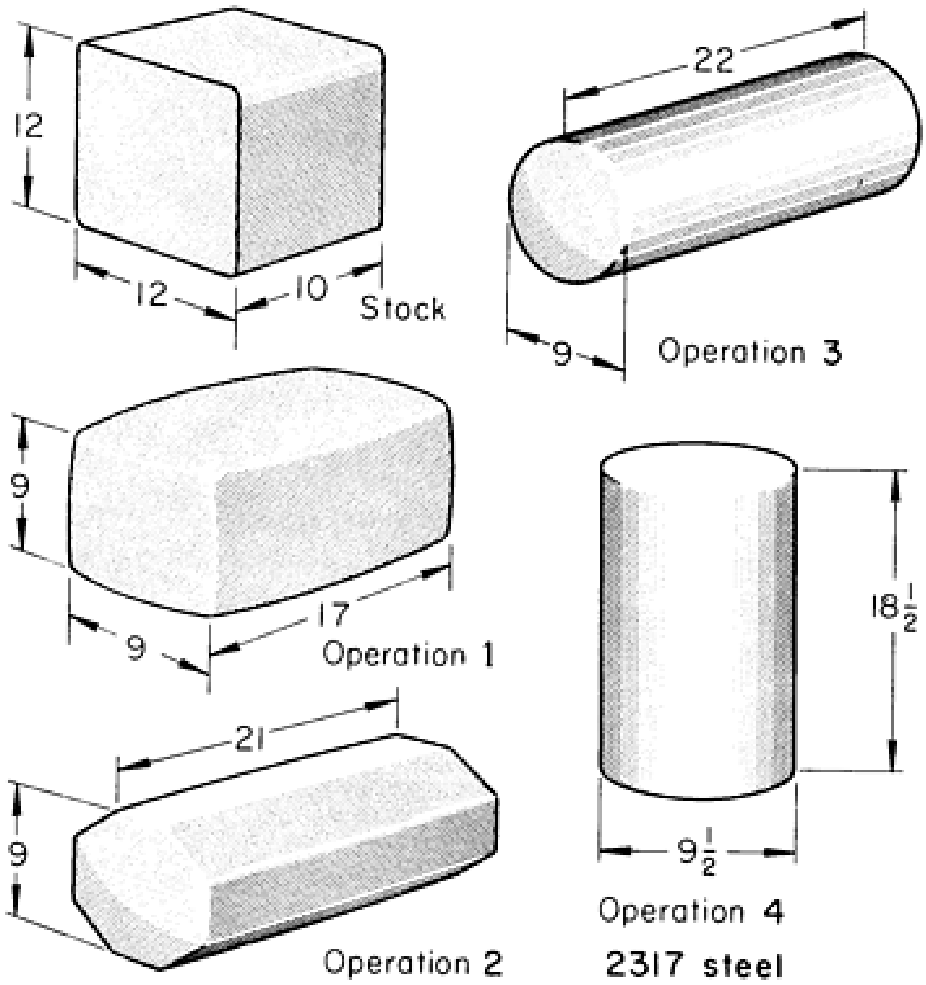



**Fig. 3.4.** Sequence of operations in the forging of a cylindrical workpiece from square stock. Dimensions in figure given in inches

***Operation 1.*** The 305 mm (12 in.) square section was hammered to a 229 mm (9 in.) square section, which increased the length to 432 mm (17 in.).
***Operation 2.*** The corners of the square were hammered to produce an octagonal shape approximately 229 mm (9 in.) across flats and 533 mm (21 in.) long.
***Operation 3.*** The octagon was rounded by successive hammer blows as the workpiece was rotated. The cylindrical forging was then approximately 559 mm (22 in.) long.
***Operation 4.*** The forging was upended and hammered lightly on both ends to flatten the bulge on the ends. This decreased the length to 470 mm (18 12 in.) and increased the diameter to 241 mm (9 12 in.).

### 3.1.5. Forging a Combined Gear Blank and Hub in Flat Dies Using a Bolster

The combined gear blank and hub forging shown in Fig. 3.5 was forged from 203 × 203 × 175 mm (8 × 8 × 7 34in.) stock in five operations, as follows.

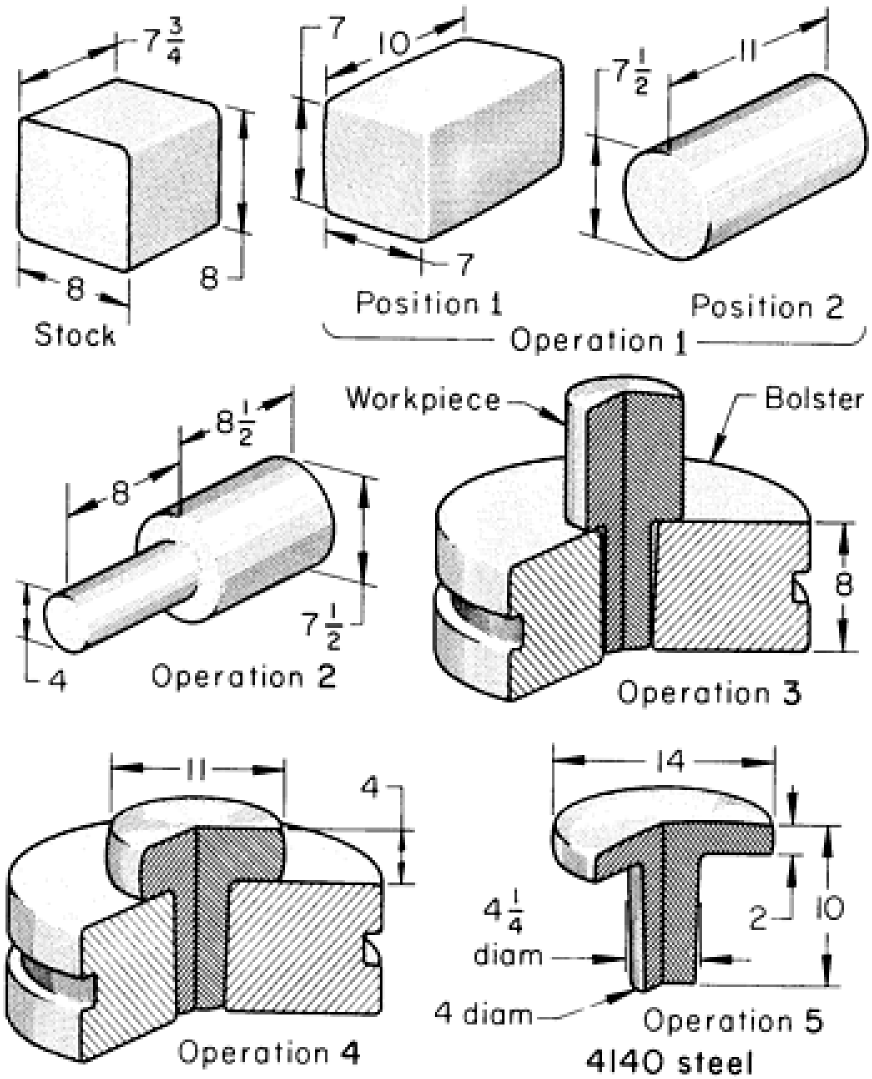
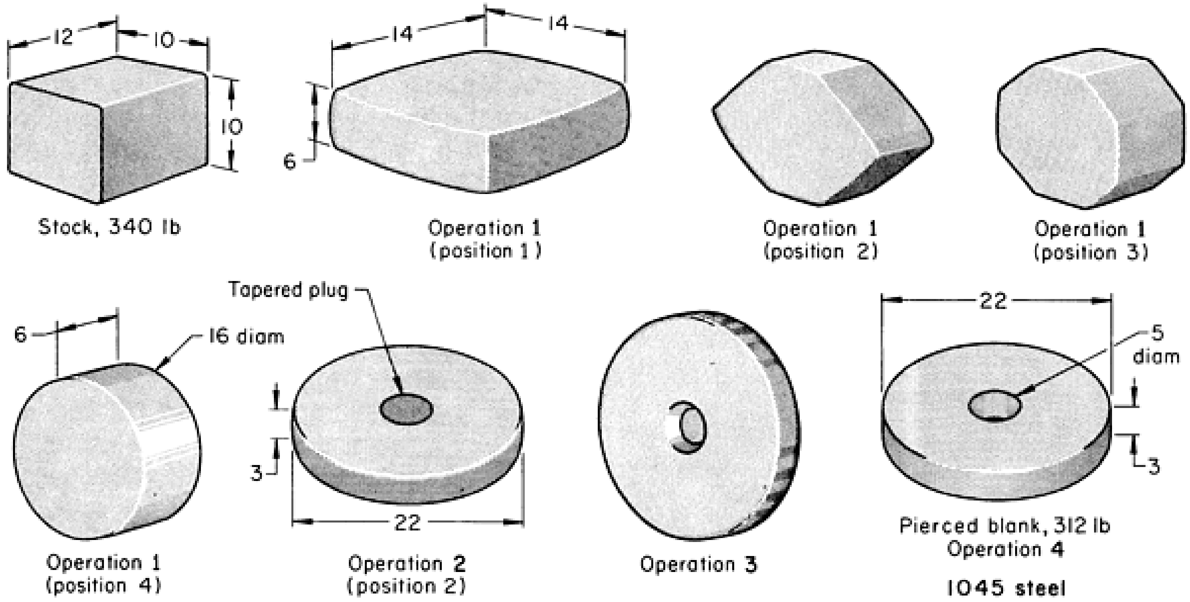



**Fig. 3.5.** Typical procedure for the forging of a gear blank and hub in open dies, featuring the use of a bolster. Dimensions in figure given in inches.

***Operation 1.*** The stock was forged to 178 × 178 × 254 mm (7 × 7 × 10 in.). This oblong was then forged into a belliedend cylinder about 191 mm (7 1 2 in.) in diameter and 279 mm (11 in.) in length, by being rotated and struck with successive hammer blows.
***Operation 2.*** A stem approximately 102 mm (4 in.) in diameter and 203 mm (8 in.) in length was drawn from 64 mm (212 in.) of the 279 mm (11 in.) length.
***Operation 3.*** The workpiece was placed vertically in a bolster, as shown in Fig. 12,
***Operation 4.*** The head was flattened (upset) until it was approximately 102 mm (4 in.) thick. The forging was then removed from the bolster and rounded up in flat dies.
***Operation 5.*** The workpiece was placed in the bolster again and forged to the dimensions shown in Fig. 12, Operation 5. The forging was fully annealed and rough machined.

### 3.1.6. Forging and Piercing a Blank for Forming a Ring

The forged and pierced blank shown in Fig. 3.6 was forged from 305 × 254 × 254 mm (12 × 10




× 10 in.) stock. The sequence of operations was as follows.

**Fig. 3.6.** Sequence of operations in the forging and piercing of a circular blank. Dimensions in figure given in inches.

***Operation 1.*** Heated stock was placed vertically on a flat die. The 305 mm (12 in.) height was reduced to 152 mm (6in.) and the 254 mm (10 in.) square cross section was increased to 356 mm (14 in.) square. The workpiece was repositioned and hammered, first to a hexagonal, next to an octagonal, and then to a round section 406 mm (16 in.) in diameter by 152 mm (6 in.) in length.
***Operation 2.*** The workpiece was flattened to a 75 mm (3 in.) thick, 559 mm (22 in.) round, and a tapered plug was centered and hammered in.
***Operation 3.*** The hot workpiece was rotated and hammered on its circumference to flatten the edge, which bulged from previous hammering, and to loosen the plug.
***Operation 4.*** The workpiece was positioned as shown in Fig. 3.6, Operation 4, and the 127 mm (5 in.) diam hole was completed by piercing from the opposite side. The pierced blank was saddle forged to a ring on a mandrel.

### 3.1.7. Radial forging

**Radial forging** is a technique that is most often used to manufacture axisymmetrical parts, such as gun barrels. Radial forging machines (Fig. 3.7) use the radial hot- or cold-forging principle with three, four, or six hammers to produce solid or hollow round, square, rectangular, or profiled sections. The machines used for forging large gun barrels are of a horizontal type and can size the bore of the gun barrel to the exact rifling that is machined on the mandrel. Products produced by radial forging often have improved mechanical and metallurgical properties as compared to those produced by other, more conventional techniques.

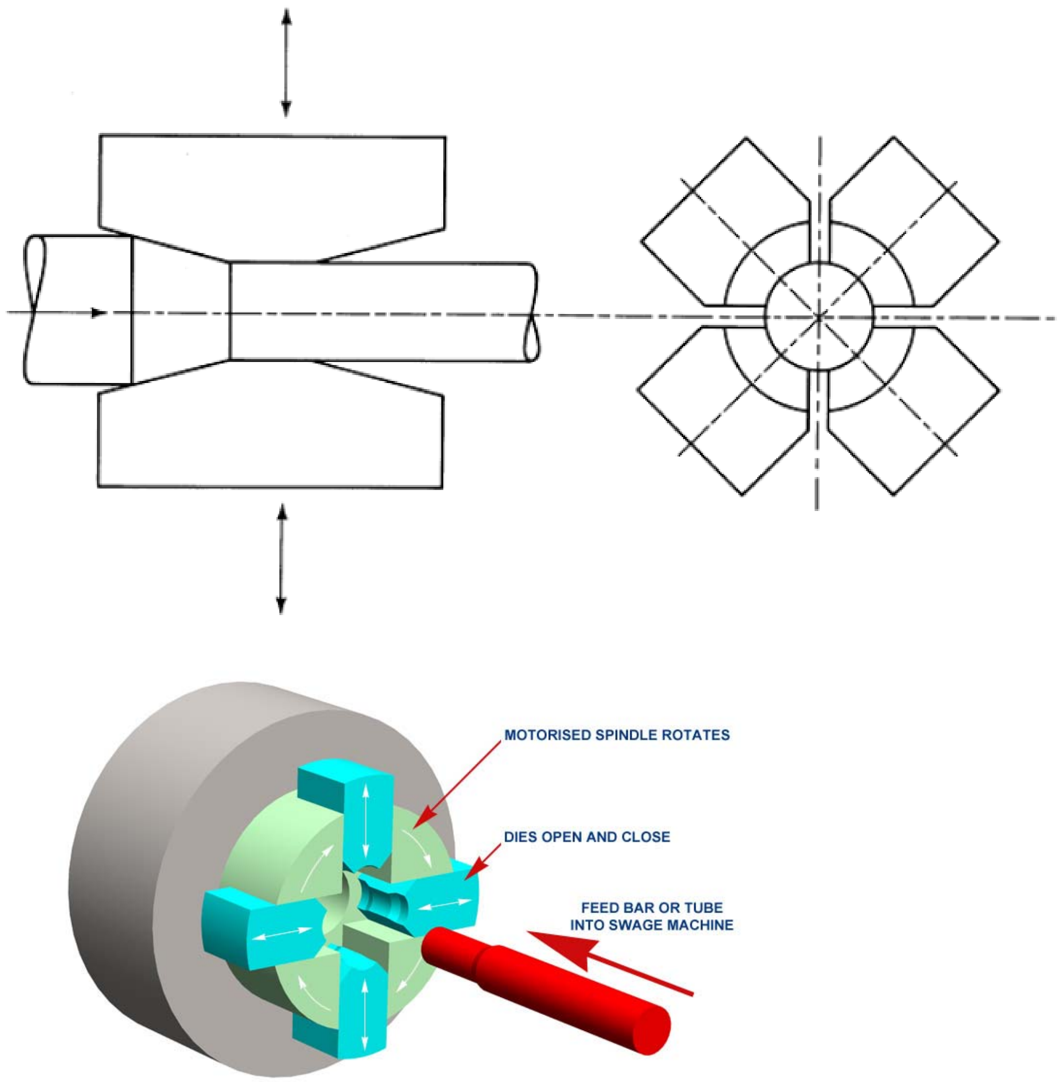



**Fig. 3.7.** Workpiece and tooling configurations for radial forging.

## 3.2. HOT CLOSED-DIE FORGING

### 3.2.1. Hot closed-die forging in presses

Closed Die Forging is the shaping of hot metal completely within the wall cavity of two dies (Fig. 3.8). The impression for the forging can be in either die or divided between a top and bottom die, shown in the diagram below.

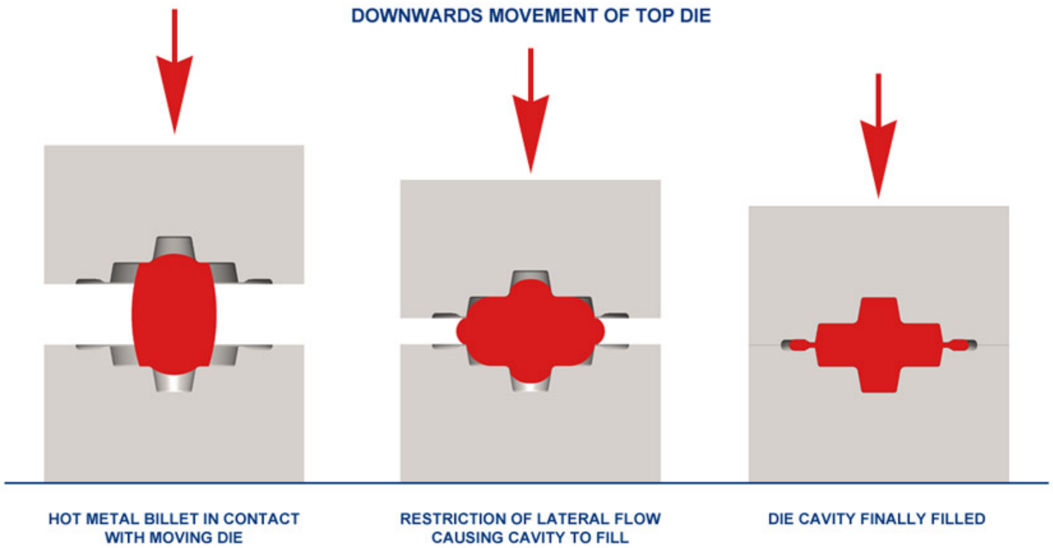



**Fig. 3.8.** Stages of hot closed-die forging

The forging of automotive connecting rods is a good example of the various steps taken to produce a closed-die forging. As shown in Fig. 3.9, the sequence begins with round bar stock. The bar stock is heated to the proper temperature, and then delivered to the press. Preliminary hot working proportions the metal for forming of the connecting rod and improves grain structure. Flash is produced in the blocking operation and appears as flat, unformed metal around the edges of the connecting rod. The final shape of the connecting rod is obtained by the impact of several additional blows from the hammer to ensure that the dies are completely filled by the hot metal. The completed part may be trimmed either hot or cold to remove flash.

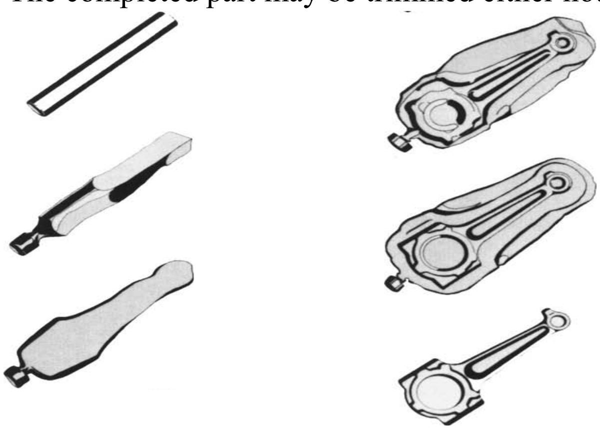


**Fig. 3.9.** Steps involved in the closed-die forging of automotive connecting rods.

### 3.2.2. Mechanical fatigue of forging dies

**Fatigue Resistance.** Mechanical fatigue of forging dies is affected by the magnitude of the applied loads, the average die temperature, and the condition of the die surface. Fatigue cracks usually initiate at points at which the stresses are highest, such as at cavities with sharp radii of curvature whose effects on the fatigue process are similar to notches (Fig. 3.10). Other regions where cracks may initiate include holes, keyways, and deep stamp markings used to identify die sets.

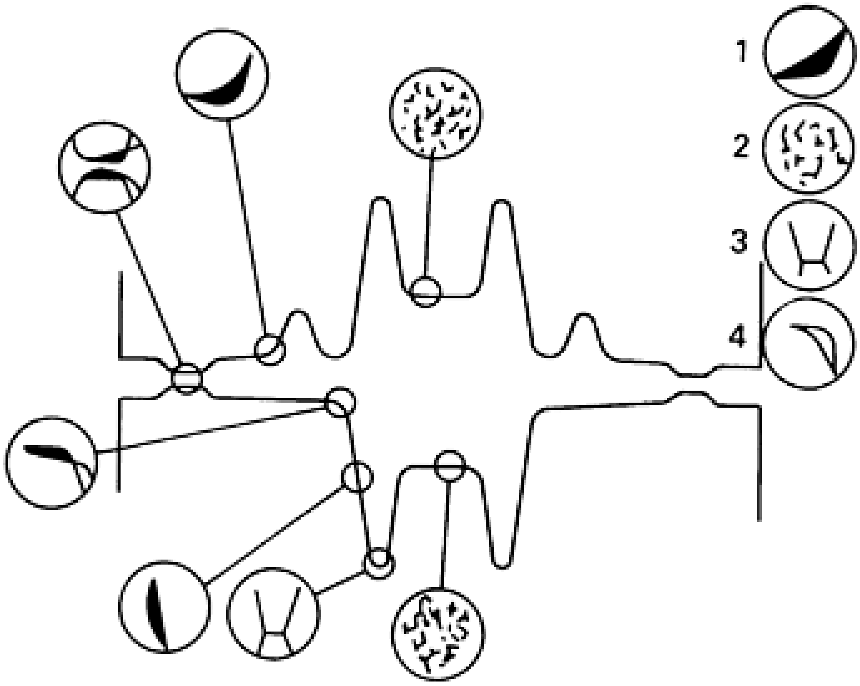



**Fig. 3.10.** Common failure mechanisms for forging dies. 1, Abrasive wear; 2, thermal fatigue; 3, mechanical fatigue; 4, plastic deformation.

Redesigning to lower the stresses is probably the best way to minimize fatigue crack initiation and growth. Redesigning may include changes in the die impression itself or modification of the flash configuration to lower the overall stresses. Surface treatments may also be beneficial in reducing fatigue-related problems. Nitriding, mechanical polishing, and shot peening are effective because they induce surface residual (compressive) stresses or eliminate notch effects, both of which delay fatigue crack initiation. On the other hand, surface treatments such as nickel, chromium, and zinc plating, which may be beneficial with respect to abrasive wear, have been found to be deleterious to fatigue properties.

## 3.3. UPSETTING

### 3.3.1. Forming a Flange a Short Distance from the End in Three Passes

The flange on the 4340 steel tube shown in Fig. 3.11 was produced in three passes in a 102 mm (4 in.) upsetter. Blanks were 718 mm (28 in.) lengths of 64 mm (2 in.) OD seamless mechanical tubing with a wall thickness of 18.2 mm (0.718 in.). The problem of upsetting the flange a short distance back from the end of the tube was solved by the use of the tooling setup illustrated in Fig. 3.11. In the first pass, the stock was upset into a cavity in the die, increasing the wall thickness by about 33%. In the second and third passes, the wall thickness through the upset was increased 39 and 23%, respectively, using heading tools that were designed to support the unforged section ahead of the flange.

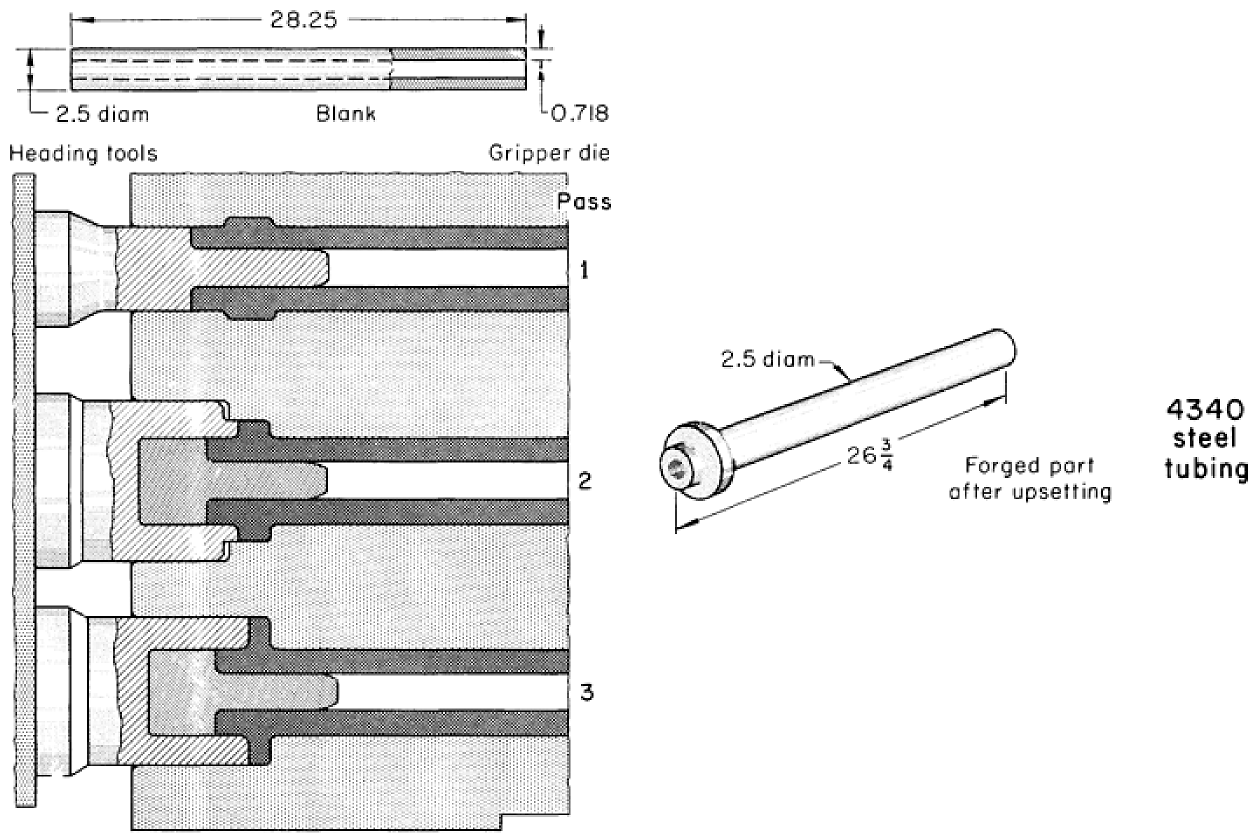



**Fig. 3.11.** Tooling setup for upsetting a flange a short distance in from the end of a tube. Dimensions given in Inches

Blanks were prepared by sawing and were heated at 1205 °C (2200 °F) in a gas-fired, slot-type, water-cooled-front furnace. Dies were made from H10 tool steel. The production rate was 55 pieces per hour, and about 6000 pieces were produced before dies required reconditioning. The die design and technique described in this example could be used for producing a flange still farther from the end of a tube. However, if the flange were considerably removed from the end, it would be necessary that only a band of the tube of proper length and location for the upset be heated, leaving both ends cool.

### 3.3.2. Upsetting and Piercing

**Upsetting and piercing** are frequently combined to promote die filling, to lessen material use, and to eliminate one or more machining operations. The maximum depth that can be pierced is limited only by the equipment available. In the following example, upsetting and piercing were combined for the production of gear blanks.

**Combined Upsetting and Piercing of Steel Gear Blank.**

The gear blank shown in Fig. 3.12 was produced more satisfactorily by upsetting and piercing than if a conventional hammer or press had been used. Less material was used, and external flash was eliminated. It was also possible to hold dimensional tolerances of +1.6, -0 mm.

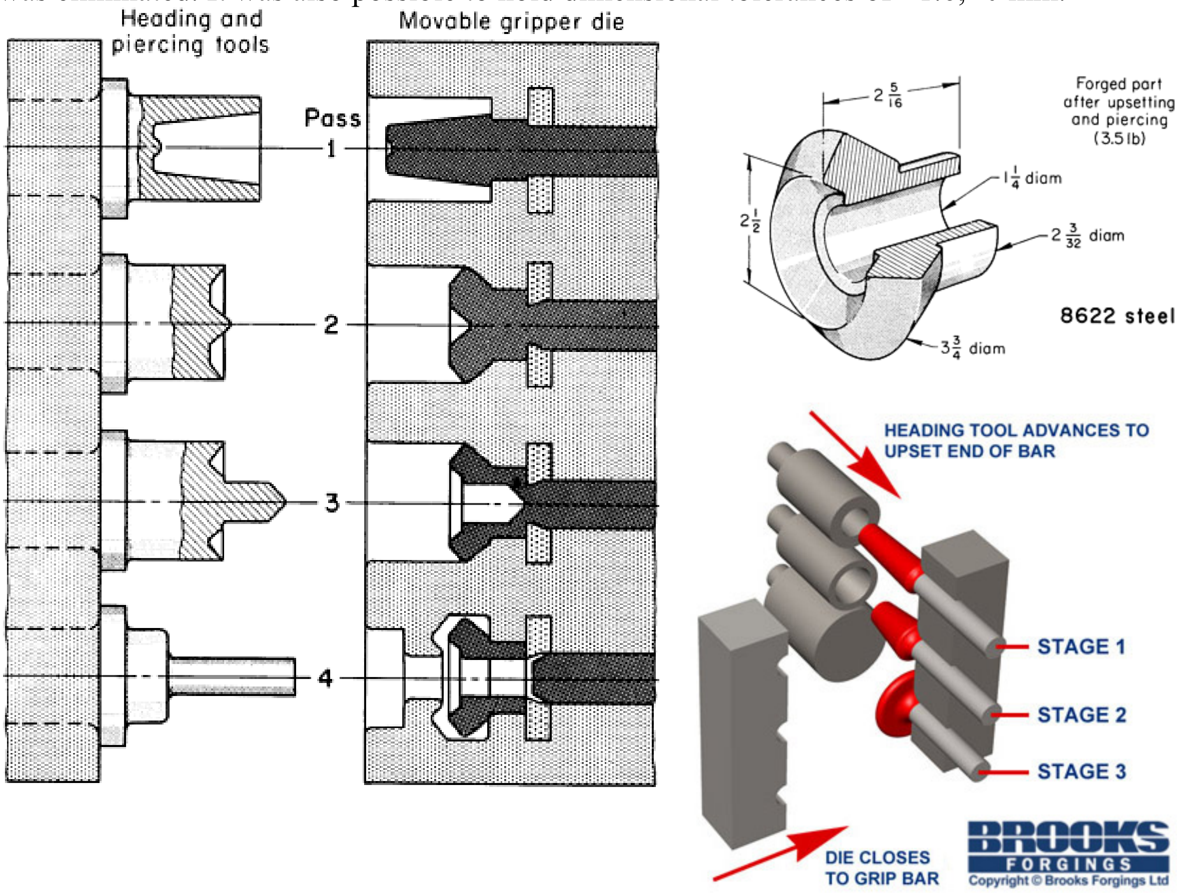



**Fig. 3.12.** Gear blank produced by four-pass hot upsetting and piercing in the tooling arrangement shown, with almost no metal loss and no trimming required. Dimensions given in inches

Forging stock consisted of 41 mm (1 in.) diam 8622 steel bars, cold sheared to 1.5 m (60 in.) lengths, each of which produced ten gear blanks. The steel was heated to 1260 °C (2300 °F) in an oil-fired batch furnace, then upset and pierced in four passes (Fig. 8) in a 102 mm (4 in.) machine. Production rate was 90 forgings per hour.

### 3.3.3. Upsetting and Piercing to Produce Bearing Races without Flash

The bearing race shown in Fig. 3.13 was upset, pierced, and cut off in two passes without flash. A 127 mm (5 in.) upsetter was used to forge the part from 3 m (10 ft) lengths of 64 mm (2 in.) diam bar stock of 4720 steel in the tooling setup shown in Fig. 9. Long bars were used to minimize loss of material from cropping; however, although 68 forgings were obtained from each 3 in (10 ft) bar, only enough bar for forging three parts was heated at a time. This method was more economical than machining the bearing races from tubing.

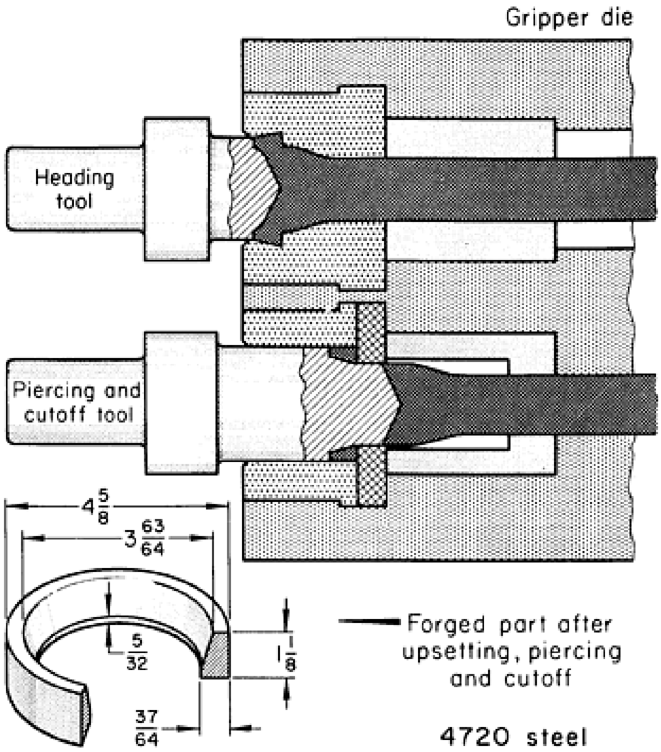



**Fig. 3.13.** Tooling setup for producing bearing races from 3-m (10-ft) lengths of 64-mm (2 -in.) diam bar by upsetting, piercing, and cut off in two passes. Dimensions given in inches.

Heating (to 1205 °C, or 2200 °F, in an oil-fired batch furnace) and upsetting were done by a two-man crew at a production rate of 150 pieces per hour. Because there were no provisions for atmosphere control in the furnace, a descaler was used to minimize carryover of scale into the upsetter. Die inserts (made solid from H11 tool steel and heat treated to 37 HRC) produced about 8000 pieces before requiring resinking to maintain the tolerances of +1.6, -0 mm specified for the forging.

## 3.4. COLD EXTRUSION

**Cold extrusion** is so called because the slug or preform enters the extrusion die at room temperature. Any subsequent increase in temperature, which may amount to several hundred degrees, is caused by the conversion of deformation work into heat. Cold extrusion involves backward (indirect), forward (direct), or combined backward and forward (indirect-direct) displacement of metal by plastic flow under steady, though not uniform, pressure. Backward displacement from a closed die is in the direction opposite to punch travel. Workpieces are often cup-shaped and have wall thicknesses equal to the clearance between the punch and die. In forward extrusion, the work metal is forced in the direction of the punch travel. These two basic methods of extrusion are sometimes combined so that some of the work metal flows backward and some forward. All three of these types of cold extrusion are shown in Fig. 3.14.

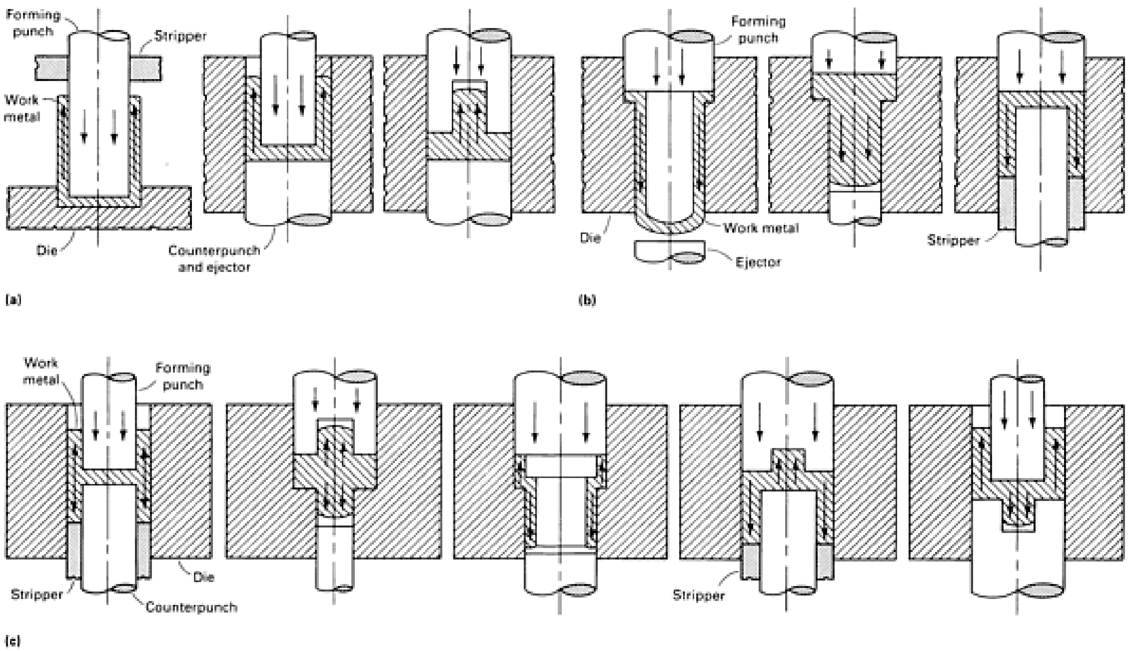



**Fig. 3.14.** Displacement of metal in cold extrusion. (a) Backward extrusion. (b) Forward extrusion. (c) Combined backward and forward extrusion

In cold extrusion, a punch applies pressure to the slug or preform, causing the work metal to flow in the required direction. The relative motion between punch and die is obtained by attaching either one (almost always the die) to the stationary bed and the other to the reciprocating ram. The axis of the machine can be vertical or horizontal. The pressure can be applied rapidly as a sharp blow, as in a crank press or header (impact extrusion), or more slowly by a squeezing action, as in a hydraulic press. The pressure exerted by the punch can be as low as 34.5 MPa (5 ksi) for soft metals or as high as 3100 MPa (450 ksi) for extrusion of alloy steel.

## 3.5. SHEARING OF PLATE AND FLAT SHEET

### 3.5.1. Straight-Knife Shearing

In straight-knife shearing, the work metal is placed between a stationary lower knife and a movable upper knife. As the upper knife is forced down, the work metal is penetrated to a specific portion of its thickness. The unpenetrated portion then fractures, and the work metal separates (Fig. 3.15). The amount of penetration depends largely on the ductility and thickness of the work metal. The knife will penetrate 30 to 60% of the work metal thickness for low-carbon steel, depending on thickness. The penetration will be greater for a more ductile metal such as copper. Conversely, the penetration will be less for metals that are harder than low-carbon steel.

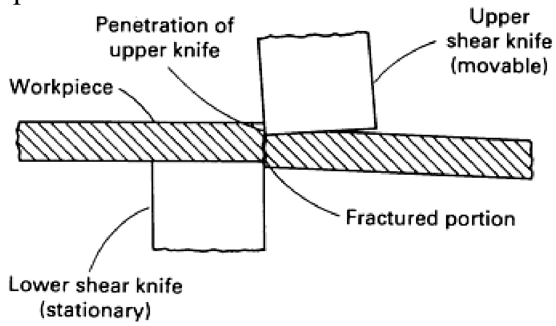



**Fig. 3.15.** The main schema of Straight-Knife Shearing

A sheared edge is characterized by the smoothness of the penetrated portion and the relative roughness of the fractured portion. Sheared edges cannot compete with machined edges, but when knives are kept sharp and in proper adjustment, it is possible to obtain sheared edges that are acceptable for a wide range of applications. The quality of sheared edges generally improves as work metal thickness decreases.

Straight-knife shearing is the most economical method of cutting straight-sided blanks from stock no more than 50 mm (2 in.) thick.

## 3.6. SHEET FORMING

### 3.6.1. Deep drawing

**Single-action dies** (Fig. 3.16a) are the simplest of all drawing dies and have only a punch and a die. A nest or locator is provided to position the blank. The drawn part is pushed through the die and is stripped from the punch by the counterbore in the bottom of the die. The rim of the cup expands slightly to make this possible. Single-action dies can be used only when the forming limit permits cupping without the use of a blankholder.

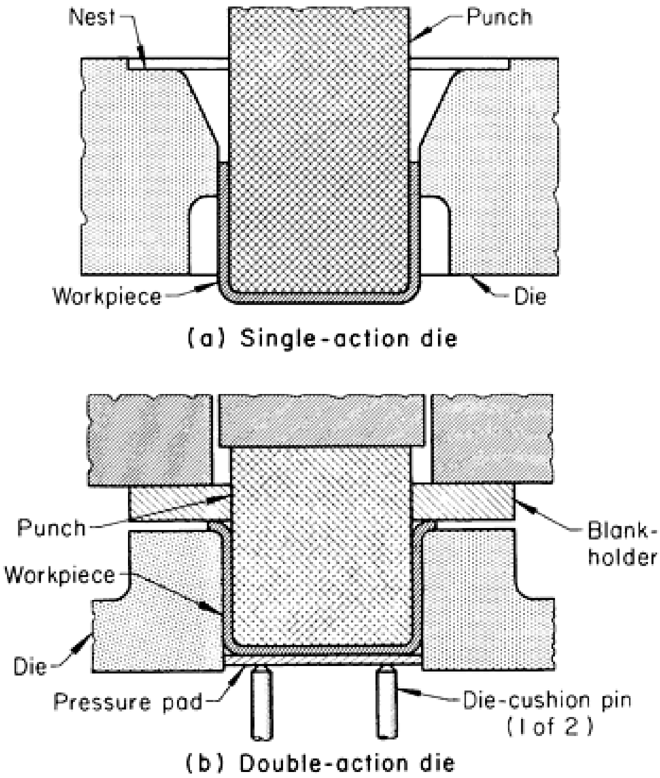



**Fig. 3.16.** Components of three types of simple dies shown in a setup used for drawing a round cup.

**Double-action dies** have a blankholder. This permits greater reductions and the drawing of flanged parts. Figure 3.16b shows a double-action die of the type used in a double-action press. In this design, the die is mounted on the lower shoe; the punch is attached to the inner, or punch slide; and the blankholder is attached to the outer slide. The pressure pad is used to hold the blank firmly against the punch nose during the drawing operation and to lift the drawn cup from the die. If a die cushion is not available, springs or air or hydraulic cylinders can be used; however, they are less effective than a die cushion, especially for deep draws.

### 3.6.2. Press-brake forming (1)

In press-brake forming, as in other forming processes, when a bend is made, the metal on the inside of the bend is compressed or shrunk, and that on the outside of the bend is stretched. The applied forces create a strain gradient across the thickness of the work metal in the area of die contact. Tensile strain occurs in the outer fiber, and compressive strain in the inner fiber; both decrease in magnitude toward the neutral axis. The setup and tooling for press-brake forming are relatively simple (Fig. 3.17). The distance the punch enters the die determines the bend angle and is controlled by the shut height of the machine. The span width of the die, or the width of the die opening, affects the force needed to bend the workpiece. The minimum width is determined by the thickness of the work and sometimes by the punch-nose radius. After the tools have been set up and the shut height has been adjusted, the press brake is cycled, and the work metal is bent to the desired angle around the nose radius of the punch.

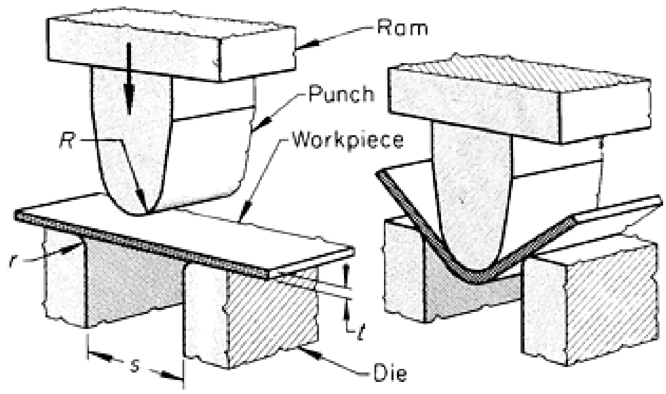



**Fig. 3.17.** Typical setup for press-brake forming in a die with a vertical opening. *R,* punch radius; *r,* die radius; *s,* span width; *t,* metal thickness.

### 3.6.3. Press-brake forming (2)

**Channel Dies.** A channel die (Fig. 3.18a) can form a channel in one stroke of the press brake, while two strokes would be required using a conventional V-die. Because it is necessary to have an ejector in the die to extract the workpiece, channel dies cost more than conventional dies. This higher cost can be justified only on the basis of large-quantity production. It is ordinarily not necessary to have a stripper on the punch, because springback usually causes the part to release. The ejector in the die may be of the spring, hydraulic, or air-return type. The stripper for the punch (if needed) is a release-wedge device or a knockout piece. The use of a channel die, regardless of production quantities, is limited by work metal
thickness, corner radii, and required flatness of the web.

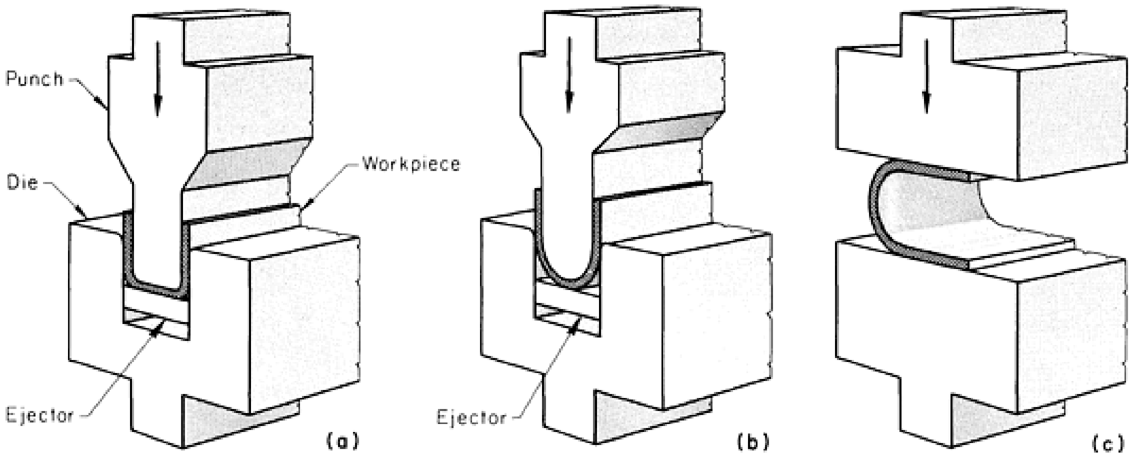
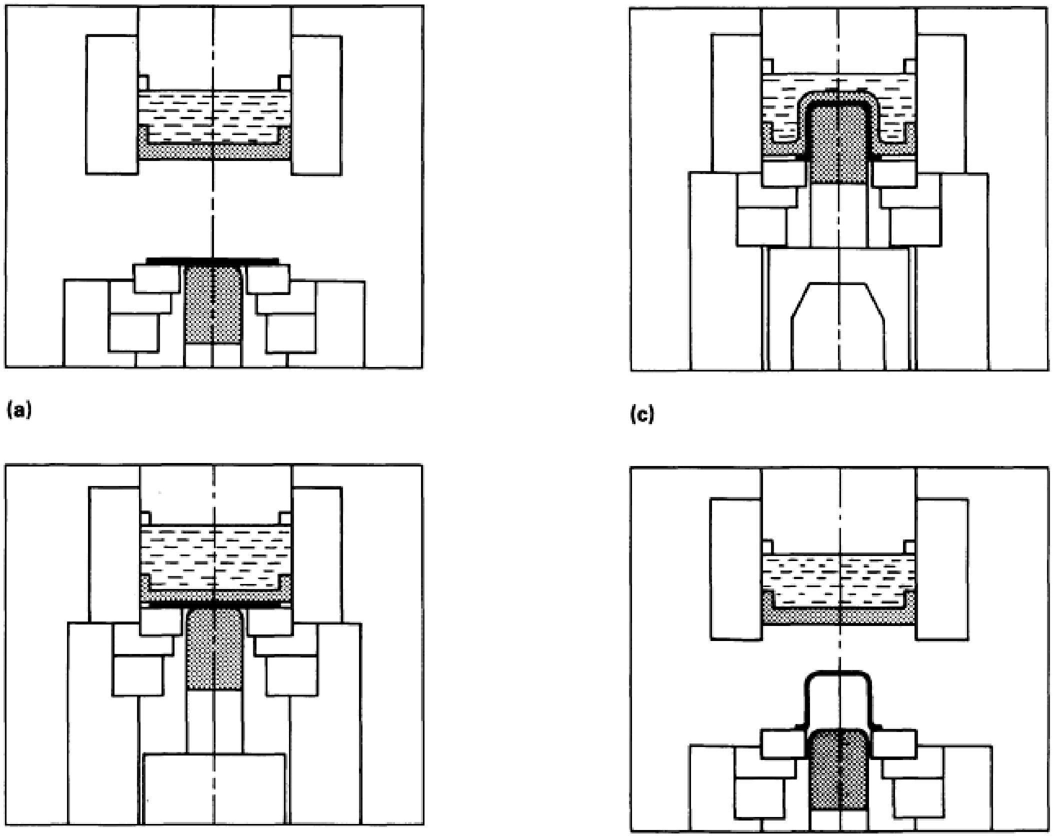



**Fig. 5** Three types of special punches and dies for press-brake forming. (a) Forming a channel in one stroke. (b) Forming a U-bend in one stroke. (c) Flattening to remove springback after U-bending.

A modification of the channel die is the U-bend die (Fig. 3.18b). Springback is a common problem with this type of die; one means of overcoming it is to perform a secondary operation on flat dies, as shown in Fig. 3.18c.

### 3.6.4. Deep Drawing Using Fluid-Forming Presses

Fluid forming (also termed hydroforming) is a deep drawing process that uses only one solid die half. Forming pressure is applied by the action of hydraulic fluid against a flexible membrane, which forces the blank to assume the shape of the rigid tool. Fluid forming can be used for deep drawing and in fact offers advantages over other forming methods. One of these is that the draw radius can be varied by changing the pressure of the hydraulic fluid during the forming operation. This makes it possible to have, for example, a large draw radius at the start of the operation that decreases as the draw continues. Thus, reductions of up to 70% in a single pass are possible when drawing cylindrical cups; for rectangular shaped parts, a height of six to eight times the corner radius can be obtained in a single operation. Figure 3.19 illustrates the deep drawing process.



(a) (c) (b) (d)

**Fig. 3.19.** The deep drawing process using the fluid-forming press: (a) the blank is placed on the blankholder; (b) the outer ram moves upward, carrying the blank; (c) oil is pumped into the inner ram system, pressing the punch upward; (d) outer ram is returned to its initial position, and the punch is retracted to allow removal of the formed part.

### 3.6.5. Superplastic forming

**Superplastic forming** is the sheet forming counterpart to isothermal forging. The isothermal, low strain rate conditions in superplastic forming result in low workpiece flow stress. Therefore, gas pressure, rather than a hard punch, is most often used to carry out a stretching-type operation; the only tooling requirement is a female die (Fig. 3.20). The very high tensile ductilities characteristic of superplastically formed sheet alloys such as Ti-6Al-4V, Zn-22Al, and aluminum alloy 7475 enable the forming of parts of very complex shape. Although cycle times for superplastic forming are relatively long (of the order of 10 min per part), economies of manufacture are realized primarily through reduced machining and assembly costs. The latter savings is a result of the fact that individual superplastically formed parts are usually used as replacements for assemblies of many separate component parts.

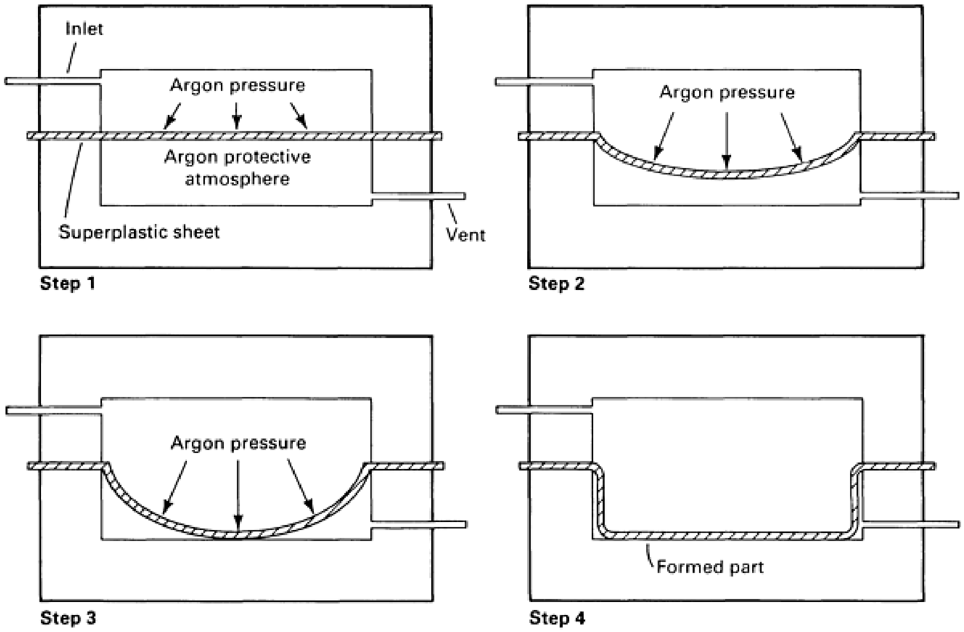



**Fig. 3.20.** Illustration of the blow-forming method of superplastic forming.

## Glossary of Terms

o **A**

- **air bend die**
- Angle-forming dies in which the metal is formed without striking the bottom of the die. Metal contact is made at only three points in the cross section: the nose of the male die and the two edges of a V-shaped die opening.
- **air-lift hammer**
- A type of gravity-drop hammer in which the ram is raised for each stroke by an air cylinder. Because length of stroke can be controlled, ram velocity and therefore the energy delivered to the workpiece can be varied. See also drop hammer and gravity hammer .
- **angle of bite**
- In the rolling of metals, the location where all of the force is transmitted through the rolls; the maximum attainable angle between the roll radius at the first contact and the line of roll centers. Operating angles less than the angle of bite are termed contact angles or rolling angles.
- **angularity**
- The conformity to, or deviation from, specified angular dimensions in the cross section of a shape or bar.
- **anvil**
- A large, heavy metal block that supports the frame structure and holds the stationary die of a forging hammer. Also, the metal block on which blacksmith forgings are made.
- **anvil cap**
- Same as sow block .
- **automatic press**
- A press with built-in electrical and pneumatic control in which the work is fed mechanically through the press in synchronism with the press action.
- **automatic press stop**
- A machine-generated signal for stopping the action of a press, usually after a complete cycle, by disengaging the clutch mechanism and engaging the brake mechanism.
- **axial rolls**
- In ring rolling , vertically displaceable, tapered rolls mounted in a horizontally displaceable frame opposite to, but on the same centerline as, the main roll and rolling mandrel. The axial rolls control ring height during rolling.

- **B**
- **backward extrusion**
- Same as indirect extrusion . See extrusion .
- **bar**
- (1) A section hot rolled from a billet to a form, such as round, hexagonal, octagonal, square, or rectangular, with sharp or rounded corners or edges and a cross-sectional area of less than 105 $cm^2$ (16 $in.^2$). (2) A solid section that is long in relationship to its cross-sectional dimensions, having a completely symmetrical cross section and a width or greatest distance between parallel faces of 9.5 mm ( in.) or more.
- **barreling**
- Convexity of the surfaces of cylindrical or conical bodies, often produced unintentionally during upsetting or as a natural consequence during compression testing. See also compression test .
- **bead**
- A narrow ridge in a sheet metal workpiece or part, commonly formed for reinforcement.
- **beaded flange**
- A flange reinforced by a low ridge, used mostly around a hole.
- **bed**
- (1) Stationary platen of a press to which the lower die assembly is attached. (2) Stationary part of the shear frame that supports the material being sheared and the fixed blade.
- **bend or twist (defect)**
- Distortion similar to warpage generally caused during forging or trimming operations. When the distortion is along the length of the part, it is termed bend; when across the width, it is termed twist. When bend or twist exceeds tolerances, it is considered a defect. Corrective action consists

of hand straightening, machine straightening, or cold restriking.

- **bend angle**
- The angle through which a bending operation is performed, that is, the supplementary angle to that formed by the two bend tangent lines or planes.
- **bending**
- The straining of material, usually flat sheet or strip metal, by moving it around a straight axis lying in the neutral plane. Metal flow takes place within the plastic range of the metal, so that the bent part retains a permanent set after removal of the applied stress. The cross section of the bend inward from the neutral plane is in compression; the rest of the bend is in tension. See also bending stress .
- **bending brake or press brake**
- A form of open-frame single-action press that is comparatively wide between the housings, with a bed designed for holding long, narrow forming edges or dies. Used for bending and forming strip, plate, and sheet (into boxes, panels, roof decks, and so on).
- **bending dies**
- Dies used in presses for bending sheet metal or wire parts into various shapes. The work is done by the punch pushing the stock into cavities or depressions of similar shape in the die or by auxiliary attachments operated by the descending punch.
- **bending rolls**
- Various types machinery equipped with two or more rolls to form curved sheet and sections.
- **bending stress**
- A stress involving tensile and compressive forces, which are not uniformly distributed. Its maximum value depends on the amount of flexure that a given application can accommodate. Resistance to bending can be termed stiffness.
- **bend radius**
- The inside radius of a bent section.
- **billet**
- (1) A semifinished section that is hot rolled from a metal ingot , with a rectangular cross section usually ranging from 105 to 230 $cm^2$ (16 to 36 $in.^2$), the width being less than twice the thickness. Where the cross section exceeds 230 $cm^2$ (36 $in.^2$), the term bloom is properly but not universally used. Sizes smaller than 105 $cm^2$ (16 $in.^2$) are usually termed bars. (2) A solid semifinished round or square product that has been hot worked by forging, rolling, or extrusion. See also bar .
- **blank**
- (1) In forming, a piece of sheet material, produced in cutting dies, that is usually subjected to further press operations. (2) A piece of stock from which a forging is made; often called a slug or multiple .
- **blankholder**
- The part of a drawing or forming die that restrains the movement of the workpiece to avoid wrinkling or tearing of the metal.
- **blanking**
- The operation of punching, cutting, or shearing a piece out of stock to a predetermined shape.
- **block**
- A preliminary forging operation that roughly distributes metal preparatory for finish .
- **block and finish**
- The forging operation in which a part to be forged is blocked and finished in one heat through the use of tooling having both a block impression and a finish impression in the same die block.
- **block, first, second, and finish**
- The forging operation in which a part to be forged is passed in progressive order through three tools mounted in one forging machine; only one heat is involved for all three operations.
- **blocker dies**
- Dies having generous contours, large radii, draft angles of 7° or more, and liberal finish allowances. See also finish allowance .
- **blocker-type forging**
- A forging that approximates the general shape of the final part with relatively generous finish allowance and radii. Such forgings are sometimes specified to reduce die costs where only a small number of forgings are desired and the cost of machining each part to its final shape is not excessive.

• **blocking**

• A forging operation often used to impart an intermediate shape to a forging, preparatory to forging of the final shape in the finishing impression of the dies. Blocking can ensure proper working of the material and can increase die life.
• **blocking impression**
• The impression that gives a forging its approximate shape.
• **bloom**
• A semifinished hot-rolled product, rectangular in cross section, produced on a blooming mill. See also billet . For steel, the width of a bloom is not more than twice the thickness, and the crosssectional area is usually not less than about 230 $cm^2$ (36 $in.^2$). Steel blooms are sometimes made by forging.
• **blooming mill**
• A primary rolling mill used to make blooms.
• **board hammer**
• A type of forging hammer in which the upper die and ram are attached to "boards" that are raised to the striking position by power-driven rollers and let fall by gravity. See also drop hammer .
• **bolster plate**
• A plate to which dies can be fastened; the assembly is secured to the top surface of a press bed. In press forging, such a plate may also be attached to the ram.
• **boss**
• A relatively short, often cylindrical protrusion or projection on the surface of a forging.
• **bottom draft**
• Slope or taper in the bottom of a forge depression that tends to assist metal flow toward the sides of depressed areas.
• **bottoming bending**
• Press-brake bending process in which the upper die (punch) enters the lower die and coins or sets the material to eliminate springback .
• **bow**
• The tendency of material to curl downward during shearing, particularly when shearing long narrow strips.
• **breakdown**
• (1) An initial rolling or drawing operation, or a series of such operations, for reducing an ingot or extruded shape to desired size before the finish reduction. (2) A preliminary press-forging operation.
• **buckling**
• A bulge, bend, kink, or other wavy condition of the workpiece caused by compressive stresses. See also compressive stress .
• **bulging**
• The process of increasing the diameter of a cylindrical shell (usually to a spherical shape) or of expanding the outer walls of any shell or box shape whose walls were previously straight.
• **bulk forming**
• Forming processes, such as extrusion, forging, rolling, and drawing, in which the input material is in billet, rod, or slab form and a considerable increase in surface-to-volume ratio in the formed part occurs under the action of largely compressive loading. Compare with sheet forming .
• **bull block**
• A machine with a power-driven revolving drum for cold drawing wire through a drawing die as the wire winds around the drum.
• **bulldozer**
• Slow-acting horizontal mechanical press with a large bed used for bending and straightening. The work is done between dies and can be performed hot or cold. The machine is closely allied to a forging machine.
• **burr**
• A thin ridge or roughness left on forgings or sheet metal blanks by cutting operations such as slitting, shearing, trimming, blanking, or sawing.
• **buster**
• A pair of shaped dies used to combine preliminary forging operations, such as edging and

blocking, or to loosen scale.

• **C**
• **camber**
• The tendency of material being sheared from sheet to bend away from the sheet in the same plane.
• **cam press**
• A mechanical press in which one or more of the slides are operated by cams; usually a doubleaction press in which the blankholder slide is operated by cams through which the dwell is obtained.
• **canning**
• (1) A dished distortion in a flat or nearly flat sheet metal surface, sometimes referred to as oil canning. (2) Enclosing a highly reactive metal within a relatively inert material for the purpose of hot working without undue oxidation of the active metal.
• **chamfer**
• (1) A beveled surface to eliminate an otherwise sharp corner. (2) A relieved angular cutting edge at a tooth corner.
• **check**
• (1) A crack in a die impression corner, generally due to forging strains or pressure, localized at some relatively sharp corner. Die blocks too hard for the depth of the die impression have a tendency to check or develop cracks in impression corners. (2) One of a series of small cracks resulting from thermal fatigue of hot forging dies.
• **chord modulus**
• The slope of the chord drawn between any two specific points on a stress-strain curve. See also modulus of elasticity .
• **circle grid**
• A regular pattern of circles, often 2.5 mm (0.1 in.) in diameter, marked on a sheet metal blank.
• **circle-grid analysis**
• The analysis of deformed circles to determine the severity with which a sheet metal blank has been deformed.
• **close-tolerance forging**
• A forging held to unusually close dimensional tolerances so that little or no machining is required after forging. See also precision forging .
• **closed-die forging**
• The shaping of hot metal completely within the walls or cavities of two dies that come together to enclose the workpiece on all sides. The impression for the forging can be entirely in either die or divided between the top and bottom dies. Impression-die forging, often used interchangeably with the term closed-die forging, refers to a closed-die operation in which the dies contain a provision for controlling the flow of excess material, or flash , that is generated. By contrast, in flashless forging, the material is deformed in a cavity that allows little or no escape of excess material.
• **closed dies**
• Forging or forming impression dies designed to restrict the flow of metal to the cavity within the die set, as opposed to open dies, in which there is little or no restriction to lateral flow.
• **closed pass**
• A pass of metal through rolls where the bottom roll has a groove deeper than the bar being rolled and the top roll has a collar fitting into the groove, thus producing the desired shape free from flash or fin .
• **cluster mill**
• A rolling mill in which each of two small-diameter work rolls is supported by two or more backup rolls.
• **cogging**
• The reducing operation in working an ingot into a billet with a forging hammer or a forging press.
• **coin straightening**
• A combination coining and straightening operation performed in special cavity dies designed to impart a specific amount of working in specified areas of a forging to relieve the stresses developed during heat treatment.

• **coining**
• (1) A closed-die squeezing operation in which all surfaces of a workpiece are confined or restrained, resulting in a well-defined imprint of the die on the work. (2) a restriking operation used to sharpen or change an existing radius or profile. Coining can be done while forgings are hot or cold and is usually performed on surfaces parallel to the parting line of the forging.
• **coining dies**
• Dies in which the coining or sizing operation is performed.
• **cold coined forging**
• A forging that has been restruck cold in order to hold closer face distance tolerances, sharpen corners or outlines, reduce section thickness, flatten some particular surface, or, in nonheattreatable alloys, increase hardness.
• **cold forming**
• See cold working
• **cold heading**
• Working metal at room temperature such that the cross-sectional area of a portion or all of the stock is increased. See also heading and upsetting .
• **cold lap**
• A flaw that results when a workpiece fails to fill the die cavity during the first forging. A seam is formed as subsequent dies force metal over this gap to leave a seam on the workpiece surface. See also cold shut .
• **cold-rolled sheet**
• A mill product produced from a hot-rolled pickled coil that has been given substantial cold reduction at room temperature. The usual end product is characterized by improved surface, greater uniformity in thickness, and improved mechanical properties as compared with hot-rolled sheet.
• **cold shut**
• (1) A fissure or lap on a forging surface that has been closed without fusion during the forging operation. (2) A folding back of metal onto its own surface during flow in the die cavity; a forging defect.
• **cold trimming**
• The removal of flash or excess metal from a forging at room temperature in a trimming press.
• **cold working**
• The plastic deformation of metal under conditions of temperature and strain rate that induce strain hardening . Usually, but not necessarily, conducted at room temperature. Also referred to as cold forming or cold forging. Contrast with hot working .
• **combination die**
• See compound die .
• **compact (noun)**
• The object produced by the compression of metal powder, generally while confined in a die.
• **compact (verb)**
• The operation or process of producing a compact; sometimes called pressing.
• **compound die**
• Any die designed to perform more than one operation on a part with one stroke of the press, such as blanking and piercing, in which all functions are performed simultaneously within the confines of the blank size being worked.
• **compressive strength**
• The maximum compressive stress a material is capable of developing. With a brittle material that fails in compression by fracturing, the compressive strength has a definite value. In the case of ductile, malleable, or semi-viscous materials (which do not fail in compression by a shattering fracture), the value obtained for compressive strength is an arbitrary value dependent on the degree of distortion that is regarded as effective failure of the material.
• **compressive stress**
• A stress that causes an elastic body to deform (shorten) in the direction of the applied load. Contrast with tensile stress .
• **compression test**
• A method for assessing the ability of a material to withstand compressive loads.
• **contour forming**

• See roll forming , stretch forming , tangent bending , and wiper forming .
• **counterblow forging equipment**
• A category of forging equipment in which two opposed rams are activated simultaneously, striking repeated blows on the workpiece at a midway point. Action is vertical or horizontal.
• **coring**
• (1) A central cavity at the butt end of a rod extrusion; sometimes called extrusion pipe . (2) A condition of variable composition between the center and surface of a unit of microstructure (such as a dendrite, grain, or carbide particle); results from nonequilibrium solidification, which occurs over a range of temperature.
• **corrugating**
• The forming of sheet metal into a series of straight, parallel alternate ridges and grooves with a rolling mill equipped with matched roller dies or a press brake equipped with specially shaped punch and die.
• **corrugations**
• Transverse ripples caused by a variation in strip shape during hot or cold reduction.
• **counterblow equipment**
• Equipment with two opposed rams that are activated simultaneously to strike repeated blows on the workpiece placed midway between them.
• **counterblow hammer**
• A forging hammer in which both the ram and the anvil are driven simultaneously toward each other by air or steam pistons.
• **counterlock**
• A jog in the mating surfaces of dies to prevent lateral die shift caused by side thrust during the forging of irregularly shaped pieces.
• **crank**
• Forging shape generally in the form of a "U" with projections at more or less right angles to the upper terminals. Cranks shapes are designated by the number of throws (for example, two-throw crank).
• **crank press**
• A mechanical press whose slides are actuated by a crankshaft.
• **crimping**
• The forming of relatively small corrugations in order to set down and lock a seam, to create an arc in a strip of metal, or to reduce an existing arc or diameter. See also corrugating .
• **crown**
• (1) The upper part (head) of a press frame. On hydraulic presses, the crown usually contains the cylinder; on mechanical presses, the crown contains the drive mechanism. See also hydraulic press and mechanical press . (2) A shape (crown) ground into a flat roll to ensure flatness of cold (and hot) rolled sheet and strip.
• **cup**
• (1) A sheet metal part; the product of the first drawing operation. (2) Any cylindrical part or shell closed at one end.
• **cup fracture (cup-and-cone fracture)**
• A mixed-mode fracture, often seen in tensile test specimens of a ductile material, in which the central portion undergoes plane-strain fracture and the surrounding region undergoes plane-stress fracture. One of the mating fracture surfaces looks like a miniature cup; it has a central depressed flat-face region surrounded by a shear lip. The other fracture surface looks like a miniature truncated cone.
• **cupping**
• (1) The first step in deep drawing . (2) Fracture of severely worked rods or wire in which one end looks like a cup and the other a cone.
• **cupping test**
• A mechanical test used to determine the ductility and stretching properties of sheet metal. It consists of measuring the maximum part depth that can be formed before fracture. The test is typically carried out by stretching the test piece clamped at its edges into a circular die using a punch with a hemispherical end. See also cup fracture , Erichsen test , and Olsen ductility test .
• **cutoff**

• A pair of blades positioned in dies or equipment (or a section of the die milled to produce the same effect as inserted blades) used to separate the forging from the bar after forging operations are completed. Used only when forgings are produced from relatively long bars instead of from individual, precut multiples or blanks. See also blank and multiple.

• **D**
• **daylight**
• The maximum clear distance between the pressing surfaces of a press when the surfaces are in the usable open position. Where a bolster plate is supplied, it is considered the pressing surface. See also shut height .
• **deep drawing**
• Characterized by the production of a parallel-wall cup from a flat blank of sheet metal. The blank may be circular, rectangular, or a more complex shape. The blank is drawn into the die cavity by the action of a punch. Deformation is restricted to the flange areas of the blank. No deformation occurs under the bottom of the punch--the area of the blank that was originally within the die opening. As the punch forms the cup, the amount of material in the flange decreases. Also called cup drawing or radial drawing.
• **deflection**
• The amount of deviation from a straight line or plane when a force is applied to a press member. Generally used to specify the allowable bending of the bed, slide, or frame at rated capacity with a load of predetermined distribution.
• **deformation limit**
• In drawing , the limit of deformation is reached when the load required to deform the flange becomes greater than the load-carrying capacity of the cup wall. The deformation limit (limiting drawing ratio, LDR) is defined as the ratio of the maximum blank diameter that can be drawn into a cup without failure, to the diameter of the punch.
• **Demarest process**
• A fluid forming process in which cylindrical and conical sheet metal parts are formed by a modified rubber bulging punch. The punch, equipped with a hydraulic cell, is placed inside the workpiece, which in turn is placed inside the die. Hydraulic pressure expands the punch.
• **developed blank**
• A sheet metal blank that yields a finished part without trimming or with the least amount of trimming.
• **die**
• A tool, usually containing a cavity, that imparts shape to solid, molten, or powdered metal primarily because of the shape of the tool itself. Used in many press operations (including blanking, drawing, forging, and forming), in die casting, and in forming green powder metallurgy compacts. Die-casting and powder metallurgy dies are sometimes referred to as molds. See also forging dies .
• **die assembly**
• The parts of a die stamp or press that hold the die and locate it for the punches.
• **die block**
• A block, often made of heat-treated steel, into which desired impressions are machined or sunk and from which closed-die forgings or sheet metal stampings are produced using hammers or presses. In forging, die blocks are usually used in pairs, with part of the impression in one of the blocks and the rest of the impression in the other. In sheet metal forming, the female die is used in conjunction with a male punch. See also closed-die forging .
• **die cavity**
• The machined recess that gives a forging or stamping its shape.
• **die check**
• A crack in a die impression due to forging and thermal strains at relatively sharp corners. Upon forging, these cracks become filled with metal, producing sharp ragged edges on the part. Usual die wear is the gradual enlarging of the die impression due to erosion of the die material, generally occurring in areas subject to repeated high pressures during forging.
• **die clearance**
• Clearance between a mated punch and die; commonly expressed as clearance per side. Also called clearance or punch-to-die clearance.

• **die closure**
• A term frequently used to mean variations in the thickness of a forging.
• **die cushion**
• A press accessory placed beneath or within a bolster plate or die block to provide an additional motion or pressure for stamping or forging operations; actuated by air, oil, rubber, springs, or a combination of these.
• **die forging**
• A forging that is formed to the required shape and size through working in machined impressions in specially prepared dies.
• **die forming**
• The shaping of solid or powdered metal by forcing it into or through the die cavity .
• **die height**
• The distance between the fixed and the moving platen when the dies are closed.
• **die holder**
• A plate or block, on which the die block is mounted, having holes or slots for fastening to the bolster plate or the bed of the press.
• **die impression**
• The portion of the die surface that shapes a forging or sheet metal part.
• **die insert**
• A relatively small die that contains part or all of the impression of a forging or sheet metal part and is fastened to the master die block .
• **die life**
• The productive life of a die impression , usually expressed as the number of units produced before the impression has worn beyond permitted tolerances.
• **die line**
• A line or scratch resulting from the use of a roughened tool or the drag of a foreign particle between tool and product.
• **die lubricant**
• In forging or forming, a compound that is sprayed, swabbed, or otherwise applied on die surfaces or the workpiece during the forging or forming process to reduce friction. Lubricants also facilitate release of the part from the dies and provide thermal insulation. See also lubricant .
• **die match**
• The alignment of the upper (moving) and lower (stationary) dies in a hammer or press. An allowance for misalignment (or mismatch) is included in forging tolerances.
• **die pad**
• A movable plate or pad in a female die; usually used for part ejection by mechanical means, springs, or fluid cushions.
• **die proof (cast)**
• a casting of a die impression made to confirm the accuracy of the impression.
• **die radius**
• The radius on the exposed edge of a deep-drawing die, over which the sheet flows in forming drawn shells.
• **die set**
• (1) The assembly of the upper and lower die shoes (punch and die holders), usually including the guide pins , guide pin bushings , and heel blocks . This assembly takes many forms, shapes, and sizes and is frequently purchased as a commercially available unit. (2) Two (or, for a mechanical upsetter, three) machined dies used together during the production of a die forging .
• **die shift**
• The condition that occurs after the dies have been set up in a forging unit in which a portion of the impression of one die is not in perfect alignment with the corresponding portion of the other die. This results in a mismatch in the forging, a condition that must be held within the specified tolerance.
• **die shoes**
• The upper and lower plates or castings that constitute a die set (punch and die holder). Also a plate or block upon which a die holder is mounted, functioning primarily as a base for the complete die assembly . This plate or block is bolted or clamped to the bolster plate or the face of the press slide .

• **die sinking**
• The machining of the die impressions to produce forgings of required shapes and dimensions.
• **die space**
• The maximum space (volume), or any part of the maximum space, within a press for mounting a die.
• **die stamping**
• The general term for a sheet metal part that is formed, shaped, or cut by a die in a press in one or more operations.
• **direct (forward) extrusion**
• See extrusion .
• **double-action mechanical press**
• A press having two independent parallel movements by means of two slides, one moving within the other. The inner slide or plunger is usually operated by a crankshaft; the outer or blankholder slide, which dwells during the drawing operation, is usually operated by a toggle mechanism or by cams. See also slide .
• **dimpling**
• (1) The stretching of a relatively small, shallow indentation into sheet metal. (2) In aircraft, the stretching of metal into a conical flange for a countersunk head rivet.
• **draft**
• The amount of taper on the sides of the forging and on projections to facilitate removal from the dies; also, the corresponding taper on the sidewalls of the die impressions. In open-die forging , draft is the amount of relative movement of the dies toward each other through the metal in one application of power. See also draft angle .
• **draft angle**
• The angle of taper, usually 5 to 7°, given to the sides of a forging and the sidewalls of the die impression. See also draft .
• **drawability**
• A measure of the formability of a sheet metal subject to a drawing process. The term usually used to indicate the ability of a metal to be deep drawn. See also drawing and deep drawing .
• **draw bead**
• An insert or riblike projection on the draw ring or hold-down surfaces that aids in controlling the rate of metal flow during deep draw operations. Draw beads are especially useful in controlling the rate of metal flow in irregularly-shaped stampings.
• **draw forming**
• A method of curving bars, tubes, or rolled or extruded sections in which the stocks is bent around a rotating form block . Stock is bent by clamping it to the form block, then rotating the form block while the stock is pressed between the form block and a pressure die held against the periphery of the form block.
• **draw marks**
• See scoring , galling , pickup , and die line .
• **draw plate**
• A circular plate with a hole in the center contoured to fit a forming punch; used to support the blank during the forming cycle.
• **draw radius**
• The radius at the edge of a die or punch over which sheet metal is drawn.
• **draw ring**
• A ring-shaped die part (either the die ring itself or a separate ring) over which the inner edge of sheet metal is drawn by the punch.
• **draw stock**
• The forging operation in which the length of a metal mass (stock) is increased at the expense of its cross section; no upset is involved. The operation includes converting ingot to pressed bar using "V," round, or flat dies.
• **drawing**
• A term used for a variety of forming operations, such as deep drawing a sheet metal blank; redrawing a tubular part; and drawing rod, wire, and tube. The usual drawing process with regard to sheet metal working in a press is a method for producing a cuplike form from a sheet metal disk by holding it firmly between blankholding surfaces to prevent the formation of wrinkles

while the punch travel produces the required shape.
• **drawing compound**
• A substance applied to prevent pickup and scoring during deep drawing or pressing operations by preventing metal-to-metal contact of the workpiece and die. Also known as die lubricant .
• **drop forging**
• The forging obtained by hammering metal in a pair of closed dies to produce the form in the finishing impression under a drop hammer ; forging method requiring special dies for each shape.
• **drop hammer**
• A term generally applied to forging hammers in which energy for forging is provided by gravity, steam, or compressed air. See also air-lift hammer , board hammer , and steam hammer .
• **drop hammer forming**
• A process for producing shapes by the progressive deformation of sheet metal in matched dies under the repetitive blows of a gravity-drop or power-drop hammer. The process is restricted to relatively shallow parts and thin sheet from approximately 0.6 to 1.6 mm (0.024 to 0.064 in.).
• **dummy block**
• In extrusion , a thick unattached disk placed between the ram and the billet to prevent overheating of the ram.
• **dwell**
• Portion of a press cycle during which the movement of a member is zero or at least insignificant. Usually refers to (1) the interval when the blankholder in a drawing operation is holding the blank while the punch is making the draw or (2) the interval between the completion of the forging stroke and the retraction of the ram.

• **E**
• **earing**
• The formation of ears or scalloped edges around the top of a drawn shell, resulting from directional differences in the plastic-working properties of rolled metal with, across, and at angles to the direction of rolling.
• **eccentric**
• The offset portion of the driveshaft that governs the stroke or distance the crosshead moves on a mechanical or manual shear.
• **eccentric gear**
• A main press-drive gear with an eccentric(s) as an integral part. The unit rotates about a common shaft, with the eccentric transmitting the rotary motion of the gear into the vertical motion of the slide through a connection.
• **eccentric press**
• A mechanical press in which an eccentric, instead of a crankshaft, is used to move the slide .
• **edger (edging impression)**
• The portion of a die impression that distributes metal during forging into areas where it is most needed in order to facilitate filling the cavities of subsequent impressions to be used in the forging sequence. See also fuller (fullering impression) .
• **edging**
• (1) In sheet metal forming, reducing the flange radius by retracting the forming punch a small amount after the stroke but before release of the pressure. (2) In rolling, the working of metal in which the axis of the roll is parallel to the thickness dimension. Also called edge rolling. (3) The forging operation of working a bar between contoured dies while turning it 90° between blows to produce a varying rectangular cross section.
• **effective draw**
• The maximum limits of forming depth that can be achieved with a multiple-action press; sometimes called maximum draw or maximum depth of draw.
• **elastic limit**
• The maximum stress a material can sustain without any permanent strain (deformation) remaining upon complete release of the stress. See also proportional limit .
• **elastic deformation**
• A change in dimensions that is directly proportional to and in phase with an increase or decrease in applied force; deformation which is recoverable when the applied force is removed.
• **elasticity**

• The property of a material by which the deformation caused by stress disappears upon removal of the stress. A perfectly elastic body completely recovers its original shape and dimensions after the release of stress.
• **electromagnetic forming**
• A process for forming metal by the direct application of an intense, transient magnetic field. The workpiece is formed without mechanical contact by the passage of a pulse of electric current through a forming coil. Also known as magnetic pulse forming.
• **elongation**
• A term used in mechanical testing to describe the amount of extension of a testpiece when stressed. See also elongation, percent .
• **elongation, percent**
• The extension of a uniform section of a specimen expressed as a percentage of the original gage length:
• where $L_0$ is the original gage length and $L_x$ is the final gage length.
• **embossing**
• A process for producing raised or sunken designs in sheet material by means of male and female dies, theoretically with no change in metal thickness. Examples are letters, ornamental pictures, and ribs for stiffening. Heavy embossing and coining are similar operations.
• **embossing die**
• A die used for producing embossed designs.
• **ejector**
• A mechanism for removing work or material from between the dies.
• **ejector rod**
• A rod used to push out a formed piece.
• **Erichsen test**
• A cupping test used to assess the ductility of sheet metal. The method consists of forcing a conical or hemispherical-ended plunger into the specimen and measuring the depth of the impression at fracture.
• **explosive forming**
• The shaping of metal parts in which the forming pressure is generated by an explosive charge. See also high-energy-rate forming .
• **extrusion**
• The conversion of an ingot or billet into lengths of uniform cross section by forcing metal to flow plastically through a die orifice. In forward (direct) extrusion, the die and ram are at opposite ends of the extrusion stock, and the product and ram travel in the same direction. Also, there is relative motion between the extrusion stock and the die. In backward (indirect) extrusion, the die is at the ram end of the stock and the product travels in the direction opposite that of the ram, either around the ram (as in the impact extrusion of cylinders such as cases for dry cell batteries) or up through the center of a hallow ram. See also hydrostatic extrusion and impact extrusion .
• **extrusion defect**
• See extrusion pipe .
• **extrusion forging**
• (1) Forcing metal into or through a die opening by restricting flow in other directions. (2) A part made by the operation.
• **extrusion billet**
• A metal slug used as extrusion stock .
• **extrusion pipe**
• A central oxide-lined discontinuity that occasionally occurs in the last 10 to 20% of an extruded bar. It is caused by the oxidized outer surface of the billet flowing around the end of the billet and into the center of the bar during the final stages of extrusion. Also called coring .
• **extrusion stock**
• A rod, bar, or other section used to make extrusions.
• **eyeleting**
• The displacing of material about an opening in sheet or plate so that a lip protruding above the surface is formed.

• **F**

• **fillet**
• The concave intersection of two surfaces. In forging, the desired radius at the concave intersection of two surfaces is usually specified.
• **fin**
• The thin projection formed on a forging by trimming or when metal is forced under pressure into hairline cracks or die interfaces.
• **finish**
• (1) The surface appearance of a product. (2) The forging operation in which the part is forged into its final shape in the finish die. If only one finish operation is scheduled to be performed in the finish die, this operation will be identified simply as finish; first, second, or third finish designations are so termed when one or more finish operations are to be performed in the same finish die.
• **finish allowance**
• The amount of excess metal surrounding the intended final shape; sometimes called clean-up allowance, forging envelope, or machining allowance.
• **finish trim**
• Flash removal from a forging; usually performed by trimming, but sometimes by band sawing or similar techniques. • **finishing dies**
• The die set used in the last forging step.
• **finishing temperature**
• The temperature at which hot working is completed.
• **finisher (finishing impression)**
• The die impression that imparts the final shape to a forged part.
• **first block, second block, and finish**
• The forging operation in which the part to be forged is passed in progressive order through three tools mounted in one forging machine; only one heat is involved for all three operations.
• **fishtail**
• (1) In roll forging , the excess trailing end of a forging. Before being trimmed off, it is often used as a tong hold for a subsequent forging operation. (2) In hot rolling or extrusion, the imperfectly shaped trailing end of a bar or special section that must be cut off and discarded as mill scrap.
• **flame straightening**
• The correction of distortion in metal structures by localized heating with a gas flame.
• **flange**
• A projecting rim or edge of a part; usually narrow and of approximately constant width for stiffening or fastening.
• **flaring**
• The forming of an outward acute-angle flange on a tubular part.
• **flash**
• Metal in excess of that required to fill the blocking or finishing forging impression of a set of dies completely. Flash extends out from the body of the forging as a thin plate at the line where the dies meet and is subsequently removed by trimming. Because it cools faster than the body of the component during forging, flash can serve to restrict metal flow at the line where dies meet, thus ensuring complete filling of the impression. See also closed-die forging .
• **flash extension**
• That portion of flash remaining on a forged part after trimming; usually included in the normal forging tolerances.
• **flash land**
• Configuration in the blocking or finishing impression of forging dies designed to restrict or to encourage the growth of flash at the parting line, whichever may be required in a particular case to ensure complete filling of the impression.
• **flash line**
• The line left on a forging after the flash has been trimmed off.
• **flash pan**
• The machined-out portion of a forging die that permits the flow through of excess metal.
• **flat die forging**
• See open-die forging .
• **flattening**

• (1) A preliminary operation performed on forging stock to position the metal for a subsequent forging operation. (2) The removal of irregularities or distortion in sheets or plates by a method such as roller leveling or stretcher leveling .
• **flattening dies**
• Dies used to flatten sheet metal hems; that is, dies that can flatten a bend by closing it. These dies consist of a top and bottom die with a flat surface that can close one section (flange) to another (hem, seam).
• **flex roll**
• A movable roll designed to push up against a sheet as it passes through a roller leveler. The flex roll can be adjusted to deflect the sheet any amount up to the roll diameter.
• **flex rolling**
• Passing sheets through a flex roll unit to minimize yield-point elongation in order to reduce the tendency for stretcher strains to appear during forming.
• **floating die**
• (1) A die mounted in a die holder or a punch mounted in its holder such that a slight amount of motion compensates for tolerance in the die parts, the work, or the press. (2) A die mounted on heavy springs to allow vertical motion in some trimming, shearing, and forming operations.
• **floating plug**
• In tube drawing, an unsupported mandrel that locates itself at the die inside the tube, causing a reduction in wall thickness while the die is reducing the outside diameter of the tube.
• **flop forging**
• A forging in which the top and bottom die impressions are identical, permitting the forging to be turned upside down during the forging operation.
• **flow lines**
• (1) Texture showing the direction of metal flow during hot or cold working. Flow lines can often be revealed by etching the surface or a section of a metal part. (2) In mechanical metallurgy, paths followed by minute volumes of metal during deformation.
• **flow through**
• A forging defect caused by metal flow past the base of a rib with resulting rupture of the grain structure.
• **fluid-cell process**
• A modification of the Guerin process for forming sheet metal, the fluid-cell process uses higher pressure and is primarily designed for forming slightly deeper parts, using a rubber pad as either the die or punch. A flexible hydraulic fluid cell forces an auxiliary rubber pad to follow the contour of the form block and exert a nearly uniform pressure at all points on the workpiece. See also fluid forming and rubber-pad forming .
• **fluid forming**
• A modification of the Guerin process, fluid forming differs from the fluid-cell process in that the die cavity, called a pressure dome, is not completely filled with rubber, but with hydraulic fluid retained by a cup-shaped rubber diaphragm. See also rubber-pad forming .
• **flying shear**
• A machine for cutting continuous rolled products to length that does not require a halt in rolling, but rather moves along the runout table at the same speed as the product while performing the cutting, and then returns to the starting point in time to cut the next piece.
• **foil**
• Metal in sheet form less than 0.15 mm (0.006 in.) thick.
• **fold**
• A forging defect caused by folding metal back onto its own surface during its flow in the die cavity.
• **follow die**
• A progressive die consisting of two or more parts in a single holder; used with a separate lower die to perform more than one operation (such as piercing and blanking) on a part in two or more stations.
• **forgeability**
• Term used to describe the relative ability of material to deform without fracture. Also describes the resistance to flow from deformation. See also formability .
• **forging**

• The process of working metal to a desired shape by impact or pressure in hammers, forging machines (upsetters), presses, rolls, and related forming equipment. Forging hammers, counterblow equipment, and high-energy-rate forging machines apply impact to the workpiece, while most other types of forging equipment apply squeeze pressure in shaping the stock. Some metals can be forged at room temperature, but most are made more plastic for forging by heating. Specific forging processes defined in this Glossary include closed-die forging , high-energy-rate forging , hot upset forging , isothermal forging , open-die forging , powder forging , precision forging , radial forging , ring rolling , roll forging , rotary forging , and rotary swaging .
• **forging billet**
• A wrong metal slug used as forging stock .
• **forging dies**
• Forms for making forgings; they generally consist of a top and bottom die. The simplest will form a completed forging in a single impression; the most complex, consisting of several die inserts, may have a number of impressions for the progressive working of complicated shapes. Forging dies are usually in pairs, with part of the impression in one of the blocks and the rest of the impression in the other block.
• **forging envelope**
• See finish allowance .
• **forging machine (upsetter or header)**
• A type of forging equipment, related to the mechanical press , in which the principal forming energy is applied horizontally to the workpiece, which is gripped and held by prior action of the dies.
• **forging plane**
• In forging, the plane that includes the principal die face and is perpendicular to the direction of ram travel. When the parting surfaces of the dies are flat, the forging plane coincides with the parting line. Contrast with parting plane .
• **forging quality**
• Term used to describe stock of sufficient quality to make it suitable for commercially satisfactory forgings.
• **forging rolls**
• Power-driven rolls used in preforming bar or billet stock that have shaped contours and notches for introduction of the work.
• **forging stock**
• A wrought rod, bar, or other section suitable for subsequent change in cross section by forging.
• **form block**
• Tooling, usually the male part, used for forming sheet metal contours; generally used in rubberpad forming .
• **form die**
• A die used to change the shape of a sheet metal blank with minimal plastic flow.
• **form rolling**
• Hot rolling to produce bars having contoured cross sections; not to be confused with the roll forming of sheet metal or with roll forging .
• **formability**
• The ease with which a metal can be shaped through plastic deformation. Evaluation of the formability of a metal involves measurement of strength, ductility, and the amount of deformation required to cause fracture. The term workability is used interchangeably with formability; however, formability refers to the shaping of sheet metal, while workability refers to shaping materials by bulk forming . See also forgeability .
• **forming**
• The plastic deformation of a billet or a blanked sheet between tools (dies) to obtain the final configuration. Metalforming processes are typically classified as bulk forming and sheet forming . Also referred to as metalworking.
• **forming limit diagram (FLD)**
• A diagram in which the major strains at the onset of necking in sheet metal are plotted vertically and the corresponding minor strains are plotted horizontally. The onset-of-failure line divides all possible strain combinations into two zones; the safe zone (in which failure during forming is not expected) and the failure zone (in which failure during forming is expected).

• **forward extrusion**
• Same as direct extrusion. See extrusion .
• **four-high mill**
• A type of rolling mill, commonly used for flat-rolled mill products, in which two large-diameter backup rolls are employed to reinforce two smaller work rolls, which are in contact with the product. Either the work rolls or the backup rolls may be driven. Compare with two-high mill and cluster mill .
• **frame**
• The main structure of a press.
• **Fuller (fullering impression)**
• Portion of the die used in hammer forging primarily to reduce the cross section and lengthen a portion of the forging stock. The fullering impression is often used in conjunction with an edger (edging impression).

• **G**
• **gage**
• (1) The thickness of sheet or the diameter of wire. The various standards are arbitrary and differ with regard to ferrous and nonferrous products as well as sheet and wire. (2) An aid for visual inspection that enables an inspector to determine more reliably whether the size or contour of a formed part meets dimensional requirements.
• **galling**
• A condition whereby excessive friction between high spots results in localized welding with subsequent spalling and further roughening of the rubbing surface(s) of one or both of two mating parts.
• **gap-frame press**
• A general classification of press in which the uprights or housings are made in the form of a letter C, thus making three sides of the die space accessible.
• **gibs**
• Guides or shoes that ensure the proper parallelism, squareness, and sliding fit between press components such as the slide and the frame. They are usually adjustable to compensate for wear and to establish operating clearance.
• **gravity hammer**
• A class of forging hammer in which energy for forging is obtained by the mass and velocity of a freely falling ram and the attached upper die. Examples are the board hammer and air-lift hammer .
• **green**
• Unsintered (not sintered).
• **green compact**
• An unsintered compact .
• **green strength**
• (1) The ability of a green compact to maintain its size and shape during handling and storage prior to sintering . (2) The tensile or compressive strength of a green compact.
• **gripper dies**
• The lateral or clamping dies used in a forging machine or mechanical upsetter.
• **Guerin process**
• A rubber-pad forming process for forming sheet metal.
• **guide**
• The parts of a drop hammer or press that guide the up-and-down motion of the ram in a true vertical direction.
• **guide pin bushings**
• Bushings, pressed into a die shoe, that allow the guide pins to enter in order to maintain punch-todie alignment.
• **guide pins**
• Hardened, ground pins or posts that maintain alignment between punch and die during die fabrication, setup, operation, and storage. If the press slide in out of alignment, the guide pins cannot make the necessary correction unless heel plates are engaged before the pins enter the bushings. See also heel block .

• **gutter**
• A depression around the periphery of a forging die impression outside the flash pan that allows space for the excess metal; surrounds the finishing impression and provides room for the excess metal used to ensure a sound forging. A shallow impression outside the parting line.

• **H**
• **hammer forging**
• Forging in which the work is deformed by repeated blows. Compare with press forging .
• **hammering**
• The working of metal sheet into a desired shape over a form or on a high-speed hammer and a similar anvil to produce the required dishing or thinning.
• **hammer**
• A machine that applies a sharp blow to the work area through the fall of a ram onto an anvil. The ram can be driven by gravity or power. See also gravity hammer and power-driven hammer .
• **hand forge (smith forge)**
• A forging operation in which forming is accomplished on dies that are generally flat. The piece is shaped roughly to the required contour with little or no lateral confinement; operations involving mandrels are included. The term hand forge refers to the operation performed, while hand forging applies to the part produced.
• **hand straightening**
• A straightening operation performed on a surface plate to bring a forging within straightness tolerance. A bottom die from a set of finish dies is often used instead of a surface plate. Hand tools used include mallets, sledges, blocks, jacks, and oil gear presses in addition to regular inspection tools.
• **Hartmann lines**
• See Lüders lines .
• **header**
• See forging machine .
• **heading**
• The upsetting of wire, rod, or bar stock in dies to form parts that usually contain portions that are greater in cross-sectional area than the original wire, rod, or bar.
• **heel block**
• A block or plate usually mounted on or attached to a lower die that serves to prevent or minimize the deflection of punches or cams.
• **hemming**
• A bend of 180° made in two steps. First, a sharp-angle bend is made; next, the bend is closed using a flat punch and a die.
• **HERF**
• A common abbreviation for high-energy-rate forging or high-energy-rate forming .
• **high-energy-rate forging**
• The production of forgings at extremely high ram velocities resulting from the sudden release of a compressed gas against a free piston. Forging is usually completed in one blow. Also known as HERF processing, high-velocity forging, and high-speed forging.
• **high-energy-rate forming**
• A group of forming processes that applies a high rate of strain to the material being formed through the application of high rates of energy transfer. See also explosive forming , highenergy-rate forging , and electromagnetic forming .
• **hold-down plate (pressure pad)**
• A pressurized plate designed to hold the workpiece down during a press operation. In practice, this plate often serves as a stripper and is also called a stripper plate.
• **hole flanging**
• The forming of an integral collar around the periphery of a previously formed hole in a sheet metal part.
• **Hooke's law**
• A material in which the stress is linearly proportional to strain is said to obey Hooke's law. See also modulus of elasticity .
• **hot forming**

• See hot working .
• **hot isostatic pressing (HIP)**
• A process for simultaneously heating and forming a power metallurgy compact in which metal powder, contained in a sealed flexible mold, is subjected to equal pressure from all directions at a temperature high enough for sintering to take place.
• **hot trimming**
• The removal of flash or excess metal from a hot part (such as a forging) in a trimming press.
• **hot upset forging**
• A bulk forming process for enlarging and reshaping some of the cross-sectional area of a bar, tube, or other product form of uniform (usually round) section. It is accomplished by holding the heated forging stock between grooved dies and applying pressure to the end of the stock, in the direction of its axis, by the use of a heading tool, which spreads (upsets) the end by metal displacement. Also called hot heading or hot upsetting. See also heading and upsetting .
• **hot working**
• The plastic deformation of metal at such a temperature and strain rate that recrystallization takes place simultaneously with the deformation, thus avoiding any strain hardening . Also referred to as hot forging and hot forming. Contrast with cold working .
• **hub**
• A boss that is in the center of a forging and forms a part of the body of the forging.
• **hubbing**
• The production of die cavities by pressing a male master plug, known as a hub , into a block of metal.
• **hydraulic hammer**
• A gravity-drop forging hammer that uses hydraulic pressure to lift the hammer between strokes.
• **hydraulic-mechanical press brake**
• A mechanical press brake that uses hydraulic cylinders attached to mechanical linkages to power the ram through its working stroke.
• **hydraulic press**
• A press in which fluid pressure is used to actuate and control the ram.
• **hydraulic press brake**
• A press brake in which the ram is actuated directly by hydraulic cylinders.
• **hydraulic shear**
• A shear in which the crosshead is actuated by hydraulic cylinders.
• **hydrostatic extrusion**
• A method of extruding a billet through a die by pressurized fluid instead of the ram used in conventional extrusion.

• **I**
• **impact extrusion**
• The process (or resultant product) in which a punch strikes a slug (usually unheated) in a confining die. The metal flow may be either between punch and die or through another opening. The impact extrusion of unheated slugs is often called cold extrusion.
• **impact line**
• A blemish on a drawn sheet metal part caused by a slight change in metal thickness. The mark is called an impact line when it results from the impact of the punch on the blank; it is called a recoil line when it results from transfer of the blank from the die to the punch during forming, or from a reaction to the blank being pulled sharply through the draw ring .
• **impression**
• A cavity machined into a forging die to produce a desired configuration in the workpiece during forging.
• **impression-die forging**
• See closed-die forging .
• **indirect (backward) extrusion**
• See extrusion .
• **ingot**
• A casting intended for subsequent rolling, forging, or extrusion.
• **ironing**

• An operation used to increase the length of a tube or cup through reduction of wall thickness and outside diameter, the inner diameter remaining unchanged.
• **isostatic pressing**
• A process for forming a powder metallurgy compact by applying pressure equally from all directions to metal powder contained in a sealed flexible mold. See also hot isostatic pressing .
• **isothermal forging**
• A hot-forging process in which a constant and uniform temperature is maintained in the workpiece during forging by heating the dies to the same temperature as the workpiece.

• **K**
• **knockout**
• A mechanism for releasing workpieces from a die.
• **knockout mark**
• A small protrusion, such as a button or ring of flash, resulting from depression of the knockout pin from the forging pressure or the entrance of metal between the knockout pin and the die.
• **knockout pin**
• A power-operated plunger installed in a die to aid removal of the finished forging.

• **L**
• **laser beam cutting**
• A cutting process that severs material with the heat obtained by directing a laser beam against a metal surface. The process can be used with or without an externally supplied shielding gas.
• **lateral extrusion**
• An operation in which the product is extruded sideways through an orifice in the container wall.
• **leveler lines**
• Lines on sheet or strip running transverse to the direction of roller leveling . These lines may be seen upon stoning or light sanding after leveling (but before drawing) and can usually be removed by moderate stretching.
• **leveling**
• The flattening of rolled sheet, strip, or plate by reducing or eliminating distortions. See stretcher leveling and roller leveling .
• **liftout**
• The mechanism also known as knockout .
• **limiting drawing ratio (LDR)**
• See deformation limit .
• **liners**
• Thin strips of metal inserted between the dies and the units into which the dies are fastened.
• **lock**
• In forging, a condition in which the flash line is not entirely in one plane. Where two or more plane changes occur, it is called compound lock. Where a lock is placed in the die to compensate for die shift caused by a steep lock, it is called a counterlock.
• **locked dies**
• Dies with mating faces that lie in more than one plane.
• **lower punch**
• The lower part of a die, which forms the bottom of the die cavity and which may or may not move in relation to the die body; usually movable in a forging die.
• **lubricant**
• A material applied to dies, molds, plungers, or workpieces that promotes the flow or metal, reduces friction and wear, and aids in the release of the finished part.
• **lubricant residue**
• the carbonaceous residue resulting from lubricant that is burned onto the surface of a hot forged part.
• **Lüders lines**
• Elongated surface markings or depressions, often visible with the unaided eye, that form along the length of a round or sheet metal tension specimen at an angel of approximately 55° to the loading axis. Caused by localized plastic deformation, they result from discontinuous (inhomogeneous) yielding. Also known as Lüders bands, Hartmann lines, Piobert lines, or

stretcher strains.

• **M**
• **mandrel**
• (1) A blunt-ended tool or rod used to retain the cavity in a hollow metal product during working. (2) A metal bar around which other metal can be cast, bent, formed, or shaped. (3) A shaft or bar for holding work to be machined.
• **mandrel forging**
• The process of rolling or forging a hollow blank over a mandrel to produce a weldless, seamless ring or tube.
• **manipulator**
• A mechanical device for handling an ingot or billet during forging.
• **Mannesmann process**
• A process for piercing tube billets in making seamless tubing. The billet is rotated between two heavy rolls mounted at an angle and is forced over a fixed mandrel.
• **Marforming process**
• A rubber-pad forming process developed to form wrinkle-free shrink flanges and deep-drawn shells. It differs from the Guerin process in that the sheet metal blank is clamped between the rubber pad and the blankholder before forming begins.
• **master block**
• A forging die block used primarily to hold insert dies. See also die insert .
• **match**
• A condition in which a point in one die half is aligned properly with the corresponding point in the opposite die half within specified tolerance.
• **matched edges (match lines)**
• Two edges of the die face that are machined exactly at 90° to each other, and from which all dimensions are taken in laying out the die impression and aligning the dies in the forging equipment.
• **matching draft**
• The adjustment of draft angles (usually involving an increase) on parts with asymmetrical ribs and sidewalls to make the surfaces of a forging meet at the parting line.
• **mechanical press**
• A forging press with an inertia flywheel, a crank and clutch, or other mechanical device to operate the ram.
• **mechanical press brake**
• A press brake using a mechanical drive consisting of a motor, flywheel, crankshaft, clutch, and eccentric to generate vertical motion.
• **mechanical upsetter**
• A three-element forging press, with two gripper dies and a forming tool, for flanging or forming relatively deep recesses.
• **mechanical working**
• The subjecting of material to pressure exerted by rolls, hammers, or presses in order to change the shape or physical properties of the material.
• **metalworking**
• See forming .
• **mill**
• (1) A factory in which metals are hot worked, cold worked, or melted and cast into standard shapes suitable for secondary fabrication into commercial products. (2) A production line, usually of four or more stands , for hot or cold rolling metal into standard shapes such as bar, rod, plate, sheet, or strip. (3) A single machine for hot rolling, cold rolling, or extruding metal; examples include blooming mill , cluster mill , four-high mill , and Sendzimir mill . (4) A shop term for a milling cutter. (5) A machine or group of machines for grinding or crushing ores and other minerals.
• **mill edge**
• The normal edge produced in rolling. Can be contrasted with a blanked or sheared edge which has a burr .
• **mill finish**

• A nonstandard (and typically nonuniform) surface finish on mill products that are delivered without being subjected to a special surface treatment (other than a corrosion-preventive treatment) after the final working or heat-treating step.
• **mill product**
• Any commercial product of a mill .
• **mill scale**
• The heavy oxide layer that forms during the hot fabrication or heat treatment of metals.
• **mismatch**
• The misalignment or error in register of a pair of forging dies; also applied to the condition of the resulting forging. The acceptable amount of this displacement is governed by blueprint or specification tolerances. Within tolerances, mismatch is a condition; in excess of tolerance, it is a serious defect. Defective forgings can be salvaged by hot-reforging operations.
• **modulus of elasticity, *E***
• The measure of rigidity or stiffness of a metal; the ratio of stress, below the proportional limit, to the corresponding strain. In terms of the stress-strain diagram , the modulus of elasticity is the slope of the stress-strain curve in the range of linear proportionality of stress to strain. Also known as Young's modulus . For materials that do not conform to Hooke's law throughout the elastic range, the slope of either the tangent to the stress-strain curve at the origin or at low stress, the secant drawn from the origin to any specified point on the stress-strain curve, or the chord connecting any two specific points on the stress-strain curve is usually taken to be the modulus of elasticity. In these cases, the modulus is referred to as the tangent modulus , secant modulus , or chord modulus , respectively.
• **multiple**
• A piece of stock for forging that is cut from bar or billet lengths to provide the exact amount of material needed for a single workpiece.
• **multiple-slide press**
• A press with individual slides, built into the main slide or connected to individual eccentrics on the main shaft, that can be adjusted to vary the length of stroke and the timing. See also slide .
• ***m*-value**
• See strain-rate sensitivity .

• **N**
• **natural draft**
• Taper on the sides of a forging, due to its shape or position in the die, that makes added draft unnecessary.
• **necking**
• (1) The reduction of the cross-sectional area of metal in a localized area by uniaxial tension or by stretching. (2) The reduction of the diameter of a portion of the length of a cylindrical shell or tube.
• **no-draft (draftless) forging**
• A forging with extremely close tolerances and little or no draft that requires minimal machining to produce the final part. Mechanical properties can be enhanced by closer control of grain flow and by retention of surface material in the final component.
• **nonfill (underfill)**
• A forging condition that occurs when the die impression is not completely filled with metal.
• ***n*-value**
• See strain-hardening exponent .

• **O**
• **offset**
• The distance along the strain coordinate between the initial portion of a stress-strain curve and a parallel line that intersects the stress-strain curve at a value of stress (commonly 0.2%) that is used as a measure of the yield strength . Used for materials that have no obvious yield point .
• **offset yield strength**
• The stress at which the strain exceeds by a specified amount (the offset ) an extension of the initial proportional portion of the stress-strain curve; expressed in force per unit area.
• **oil canning**

• Same as canning .
• **Olsen ductility test**
• A cupping test in which a piece of sheet metal, restrained except at the center, is deformed by a standard steel ball until fracture occurs. The height of the cup at the time of fracture is a measure of the ductility.
• **open dies**
• Dies with flat surfaces that are used for performing stock or producing hand forgings.
• **open-die forging**
• The hot mechanical forming of metals between flat or shaped dies in which metal flow is not completely restricted. Also known as hand or smith forging. See also hand forge (smith forge) .
• **orbital forging**
• See rotary forging .

• **P**
• **pad**
• The general term used for that part of a die which delivers holding pressure to the metal being worked.
• **pancake forging**
• A rough forged shape, usually flat, that can be obtained quickly with minimal tooling. Considerable machining is usually required to attain the finish size.
• **parting line**
• The line among the surface of a forging where the dies meet, usually at the largest cross section of the part. Flash is formed at the parting line.
• **parting plane**
• The plane that includes the principal die face and is perpendicular to the direction of ram travel. When parting surfaces of the dies are flat, the parting plane coincides with the parting line. Also referred to as the forging plane.
• **pass**
• (1) A single transfer of metal through a stand of rolls. (2) The open space between two grooved rolls through which metal is processed.
• **perforating**
• The punching of many holes, usually identical and arranged in a regular pattern, in a sheet, workpiece blank, or previously formed part. The holes are usually round, but may be any shape. The operation is also called multiple punching. See also piercing .
• **permanent set**
• The deformation or strain remaining in a previously stressed body after release of the load.
• **pickup**
• Small particles of oxidized metal adhering to the surface of a mill product .
• **piercing**
• The general term for cutting (shearing or punching) openings, such as holes and slots, in sheet material, plate, or parts. This operation is similar to blanking ; the difference is that the slug or piece produced by piercing is scrap, while the blank produced by blanking is the useful part.
• **pinch trimming**
• The trimming of the edge of a tubular part or shell by pushing or pinching the flange or lip over the cutting edge of a stationary punch or over the cutting edge of a draw punch.
• **Piobert lines**
• See Lüders lines .
• **plastic deformation**
• The permanent (inelastic) distortion of metals under applied stresses that strain the material beyond its elastic limit . The ability of metals to flow in a plastic manner without fracture is the fundamental basis for all metal-forming processes.
• **plastic flow**
• The phenomenon that takes place when metals or other substances are stretched or compressed permanently without rupture.
• **plastic-strain ratio (*r*-value)**
• The ratio of the true width strain to the true thickness strain in a sheet tensile test, $r = {}_{w}/ {}_{t}$. A formability parameter that relates to drawing, it is also known as the anisotropy factor. A high *r*value

indicates a material with good drawing properties.
• **plasticity**
• The ability of a metal to undergo permanent deformation without rupture.
• **platen**
• The sliding member, slide, or ram of a press.
• **plug**
• (1) A rod or mandrel over which a pierced tube is forced. (2) A rod or mandrel that fills a tube as it is drawn through a die. (3) A punch or mandrel over which a cup is drawn. (4) A protruding portion of a die impression for forming a corresponding recess in the forging. (5) A false bottom in a die.
• **Poisson's ratio,**
• The absolute value of the ratio of transverse (lateral) strain to the corresponding axial strain resulting from uniformly distributed axial stress below the proportional limit of the material in a tensile test.
• **powder forging**
• The plastic deformation of a powder metallurgy compact or preform into a fully dense finished shape by using compressive force; usually done hot and within closed dies.
• **power-driven hammer**
• A forging hammer with a steam or air cylinder for raising the ram and augmenting its downward blow.
• **precision forging**
• A forging produced to closer tolerances than normally considered standard by the industry.
• **preform**
• (1) The forging operation in which stock is preformed or shaped to a predetermined size and contour prior to subsequent die forging operations. When a preform operation is required, it will precede a forging operation and will be performed in conjunction with the forging operation and in the same heat. (2) The initially pressed powder metallurgy compact to be subjected to repressing .
• **press**
• A machine tool with a stationary bed and a slide or ram that has reciprocating motion at right angles to the bed surface; the slide is guided in the frame of the machine.
• **press brake**
• An open-frame single-action press used to bend, blank, corrugate, curl, notch, perforate, pierce, or punch sheet metal or plate.
• **press capacity**
• The rated force a press is designed to exert at a predetermined distance above the bottom of the stroke of the slide.
• **press forging**
• The forging of metal between dies by mechanical or hydraulic pressure; usually accomplished with a single work stroke of the press for each die station.
• **press forming**
• Any sheet metal forming operation performed with tooling by means of a mechanical or hydraulic press.
• **press load**
• The amount of force exerted in a given forging or forming operation.
• **press slide**
• See slide .
• **pressure plate**
• A plate located beneath the bolster that acts against the resistance of a group of cylinders mounted to the pressure plate to provide uniform pressure throughout the press stroke when the press is symmetrically loaded.
• **profile (contour) rolling**
• In ring rolling , a process used to produce seamless rolled rings with a predesigned shape on the outside or the inside diameter, requiring less volume of material and less machining to produce finished parts.
• **progression**
• The constant dimension between adjacent stations in a progressive die.

• **progressive die**
• A die with two or move stations arranged in line for performing two or more operations on a part; one operation is usually performed at each station.
• **progressive forming**
• Sequential forming at consecutive stations with a single die or separate dies.
• **proof**
• Any reproduction of a die impression in any material; often a lead or plaster cast. See also die proof .
• **proof load**
• A predetermined load, generally some multiple of the service load, to which a specimen or structure is submitted before acceptance for use.
• **proof stress**
• (1) The stress that will cause a specified small permanent set in a material. (2) A specified stress to be applied to a member or structure to indicate its ability to withstand service loads.
• **proportional limit**
• The greatest stress a material is capable of developing without a deviation from straight-line proportionality between stress and strain. See also elastic limit and Hooke's law .
• **punch**
• (1) The male part of a die--as distinguished from the female part, which is called the die. The punch is usually the upper member of the complete die assembly and is mounted on the slide or in a die set for alignment (except in the inverted die). (2) In double-action draw dies, the punch is the inner portion of the upper die, which is mounted on the plunger (inner slide) and does the drawing. (3) The act of piercing or punching a hole. Also referred to as punching .
• **punching**
• The die shearing of a closed contour in which the sheared out sheet metal part is scrap.

• **R**
• **radial draw forming**
• The forming of sheet metals by the simultaneous application of tangential stretch and radial compression forces. The operation is done gradually by tangential contact with the die member. This type of forming is characterized by very close dimensional control.
• **radial forging**
• A process using two or move moving anvils or dies for producing shafts with constant or varying diameters along their length or tubes with internal or external variations in diameter. Often incorrectly referred to as rotary forging .
• **radial roll (main roll, king roll)**
• The primary driven roll of the rolling mill for rolling rings in the radial pass. The roll is supported at both ends.
• **radial rolling force**
• The action produced by the horizontal pressing force of the rolling mandrel acting against the ring and the main roll.
• **radius**
• To remove the sharp edge or corner of forging stock by means of a radius or form tool.
• **ram**
• The moving or falling part of a drop hammer or press to which one of the dies is attached; sometimes applied to the upper flat die of a steam hammer. Also referred to as the slide .
• **recoil line**
• See impact line .
• **redrawing**
• The second and successive deep-drawing operations in which cuplike shells are deepened and reduced in cross-sectional dimensions.
• **reduction**
• In cupping and deep drawing, a measure of the percentage of decrease from blank diameter to cup diameter, or of the diameter reduction in redrawing. (2) In forging, extrusion, rolling, and drawing, either the ratio of the original to the final cross-sectional area or the percentage of decreased in cross-sectional area.
• **reduction in area**

• The difference between the original cross-sectional area and the smallest area at the point of rupture in a tensile test; usually stated as a percentage of the original area.
• **repressing**
• The application of pressure to a sintered compact; usually done to improve a physical or mechanical property or for dimensional accuracy.
• **rerolling quality**
• Rolled billets from which the surface defects have not been removed or completely removed.
• **reset**
• The realigning or adjusting of dies or tools during a production run; not to be confused with the operation setup that occurs before a production run.
• **residual stress**
• Stresses that remain within a body as the result of nonuniform plastic deformation or heating and cooling.
• **restriking**
• (1) The striking of a trimmed but slightly misaligned or otherwise faulty forging with one or more blows to improve alignment, improve surface condition, maintain close tolerances, increase hardness, or effect other improvements. (2) A sizing operation in which coining or stretching is used to correct or alter profiles and to counteract distortion. (3) A salvage operation following a primary forging operation in which the parts involved are rehit in the same forging die in which the pieces were last forged.
• **reverse drawing**
• Redrawing of a sheet metal part in a direction opposite to that of the original drawing.
• **reverse flange**
• A sheet metal flange made by shrinking, as opposed to one formed by stretching.
• **rib**
• (1) A long V-shaped or radiused indentation used to strengthen large sheet metal panels. (1) A long, usually thin protuberance used to provide flexural strength to a forging (as in a rib-web forging).
• **ring rolling**
• The process of shaping weldless rings from pierced disks or shaping thick-wall ring-shaped blanks between rolls that control wall thickness, ring diameter, height, and contour.
• **rod**
• A solid round section 9.5 mm ( in.) or greater in diameter, whose length is great in relation to its diameter.
• **roll bending**
• The curving of sheets, bars, and sections by means of rolls.
• **roll flattening**
• The flattening of sheets that have been rolled in packs by passing them separately through a twohigh cold mill with virtually no deformation. Not to be confused with roller leveling .
• **roll forging**
• A process of shaping stock between two driven rolls that rotate in opposite directions and have one or more matching sets of grooves in the rolls; used to produce finished parts of preforms for subsequent forging operations.
• **roll forming**
• Metal forming through the use of power-driven rolls whose contour determines the shape of the product; sometimes used to denote power spinning .
• **roll threading**
• The production of threads by rolling the piece between two grooved die plates, one of which is in motion, or between rotating grooved circular rolls.
• **roller leveler breaks**
• Obvious transverse breaks on sheet metal usually about 3 to 6 mm ( to in.) apart that the caused by the sheet fluting during roller leveling . These will not be removed by stretching.
• **roller leveling**
• Leveling by passing flat sheet metal stock through a machine having a series of small-diameter staggered rolls that are adjusted to produce repeated reverse bending.
• **rolling**
• The reduction of the cross-sectional area of metal stock, or the general shaping of metal products,

through the use of rotating rolls.
• **rolling mandrel**
• In ring rolling, a vertical roll of sufficient diameter to accept various sizes of ring blanks and to exert rolling force on an axis parallel to the main roll.
• **rolling mills**
• Machines used to decrease the cross-sectional area of metal stock and to produce certain desired shapes as the metal passes between rotating rolls mounted in a framework comprising a basic unit called a stand . Cylindrical rolls produce flat shapes; grooved rolls produce rounds, squares, and structural shapes. See also four-high mill , Sendzimir mill , and two-high mill .
• **roll straightening**
• The straightening of metal stock of various shapes by passing it through a series of staggered rolls (the rolls usually being in horizontal and vertical planes) or by reeling in two-roll straightening machines.
• **rotary forging**
• A process in which the workpiece is pressed between a flat anvil and a swiveling (rocking) die with a conical working face; the platens move toward each other during forging. Also called orbital forging. Compare with radial forging .
• **rotary shear**
• A sheet metal cutting machine with two rotating-disk cutters mounted on parallel shafts driven in unison.
• **rotary swager**
• A swaging machine consisting of a power-driven ring that revolves at high speed, causing rollers to engage cam surfaces and force the dies to deliver hammerlike blows on the work at high frequency. Both straight and tapered sections can be produced.
• **rotary swaging**
• A bulk forming process for reducing the cross-sectional area or otherwise changing the shape of bars, tubes, or wires by repeated radial blows with one or more pairs of opposed dies.
• **rough blank**
• A blank for a forming or drawing operation, usually of irregular outline, with necessary stock allowance for process metal, which is trimmed after forming or drawing to the desired size.
• **roughing stand**
• The first stand (or several stands) of rolls through which a reheated billet passes in front of the finishing stands. See also rolling mills and stand .
• **rubber forming**
• A sheet metal forming process in which rubber is used as a functional die part.
• **rubber-pad forming**
• A sheet metal forming operation for shallow parts in which a confined, pliable rubber pad attached to the press slide (ram) is forced by hydraulic pressure to become a mating die for a punch or group of punches placed on the press bed or baseplate. Developed in the aircraft industry for the limited production of a large number of diversified parts, the process is limited to the forming of relatively shallow parts, normally not exceeding 40 mm(1.5 in.) deep. Also known as the Guerin process. Variations of the Guerin process include the Marforming process , the fluid-cell process , and fluid forming.

• **S**
• **scoring**
• (1) The marring or scratching of any formed part by metal pickup on the punch or die. (2) The reduction in thickness of a material along a line to weaken it intentionally along that line.
• **screw press**
• A high-speed press in which the ram is activated by a large screw assembly powered by a drive mechanism.
• **secant modulus**
• The slope of the secant drawn from the origin to any specified point on the stress-strain curve. See also modulus of elasticity .
• **segment die**
• Same as split die .
• **semifinisher**

• An impression in a series of forging dies that only approximates the finish dimensions of the forging. Semifinishers are often used to extend die life or the finishing impression, to ensure proper control of grain flow during forging, and to assist in obtaining desired tolerances.
• **Sendzimir mill**
• A type of cluster mill with small-diameter work rolls and larger-diameter backup rolls, backed up by bearings on a shaft mounted eccentrically so that it can be rotated to increase the pressure between the bearing and the backup rolls. Used to roll precision and very thin sheet and strip.
• **shank**
• The portion of a die or tool by which it is held in position in a forging unit or press.
• **shear**
• (1) A machine or tool or cutting metal and other material by the closing motion of two sharp, closely adjoining edges; for example, squaring shear and circular shear. (2) An inclination between two cutting edges, such as between two straight knife blades or between the punch cutting edge and the die cutting edge, so that a reduced area will be cut each time. This lessens the necessary force, but increases the required length of the working stroke. This method is referred to as angular shear. (3) The act of cutting by shearing dies or blades, as in a squaring shear. (4) The type of force that causes or tends to cause two contiguous parts of the same body to slide relative to each other in a direction parallel to their plane of contact.
• **shear strength**
• The maximum shear stress a material can sustain. Shear strength is calculated from the maximum load during a shear or torsion test and is based on the original dimensions of the cross section of the specimen.
• **shear stress**
• (1) A stress that exists when parallel planes in metal crystals slide across each other. (2) The stress component tangential to the plane on which the forces act.
• **shearing**
• The parting of material that results when one blade forces the material past an opposing blade.
• **sheet**
• Any material or piece of uniform thickness and of considerable length and width as compared to its thickness. With regard to metal, such pieces under 6.5 mm ( in.) thick are called sheets, and those 6.5 mm ( in.) thick and over are called plates. Occasionally, the limiting thickness for steel to be designated as sheet steel is No. 10 Manufacturer's Standard Gage for sheet steel, which is 3.42 mm (0.1345 in.) thick.
• **sheet forming**
• The plastic deformation of a piece of sheet metal by tensile loads into a three-dimensional shape, often without significant changes in sheet thickness or surface characteristics. Compare with bulk forming .
• **shim**
• A thin piece of material used between two surfaces to obtain a proper fit, adjustment, or alignment.
• **shrinkage**
• The contraction of metal during cooling after hot forging. Die impressions are made oversize according to precise shrinkage scales to allow the forgings to shrink to design dimensions and tolerances.
• **shut height**
• For a press, the distance from the top of the bed to the bottom of the slide with the stroke down and adjustment up. In general, it is the maximum die height that can be accommodated for normal operation, taking the bolster plate into consideration.
• **side thrust**
• The lateral force exerted between the dies by reaction of a forged piece on the die impressions.

• **single-stand mill**
• A rolling mill designed such that the product contacts only two rolls at a given moment. Contrast with tandem mill .
• **sinking**
• The operation of machining the impression of a desired forging into die blocks.
• **sintering**

• The densification and bonding of adjacent particles in a powder mass or compact by heating to a temperature below the melting point of the main constituent.
• **sizing**
• (1) Secondary forming or squeezing operations needed to square up, set down, flatten, or otherwise correct surfaces to produce specified dimensions and tolerances. See restriking . (2) Some burnishing, broaching, drawing, and shaving operations are also called sizing. (3) A finishing operation for correcting ovality in tubing. (4) Final pressing of a sintered powder metallurgy part.
• **slab**
• A flat-shaped semifinished rolled metal ingot with a width not less than 250 mm (10 in.) and a cross-sectional area not less than 105 $cm^2$ (16 $in.^2$).
• **slabbing**
• The hot working of an ingot to a flat rectangular shape.
• **slide**
• The main reciprocating member of a press, guided in the press frame, to which the punch or upper die is fastened; sometimes called the ram . The inner slide of a double-action press is called the plunger or punch-holder slide; the outer slide is called the blankholder slide. The third slide of a triple-action press is called the lower slide, and the slide of a hydraulic press is often called the platen.
• **slide adjustment**
• The distance that a press slide position can be altered to change the shut height of the die space. The adjustment can be made by hand or by power mechanism.
• **slitting**
• Cutting or shearing along single lines to cut strips from a sheet or to cut along lines of a given length or contour in a sheet or workpiece.
• **slug**
• (1) The metal removed when punching a hole in a forging; also termed punchout. (2) The forging stock for one workpiece cut to length. See also blank .
• **smith forging**
• See hand forge (smith forge) .
• **sow block**
• A block of heat-treated steel placed between the anvil of the hammer and the forging die to prevent undue wear to the anvil. Sow blocks are occasionally used to hold insert dies. Also called anvil cap.
• **spinning**
• The forming of a seamless hollow metal part by forcing a rotating blank to conform to a shaped mandrel that rotates concentrically with the blank. In the typical application, a flat-rolled metal blank is forced against the mandrel by a blunt, rounded tool; however, other stock (notably, welded or seamless tubing) can be formed. A roller is sometimes used as the working end of the tool.
• **split die**
• A die made of parts that can be separated for ready removal of the workpiece. Also known as segment die.
• **springback**
• (1) The elastic recovery of metal after stressing. (2) The extent to which metal tends to return to its original shape or contour after undergoing a forming operation. This is compensated for by overbending or by a secondary operation of restriking .
• **stamping**
• The general term used to denote all sheet metal pressworking.
• **stand**
• A piece of rolling mill equipment containing one set of work rolls. In the usual sense, any pass of a cold- or hot-rolling mill. See also rolling mills .
• **steam hammer**
• A type of drop hammer in which the ram is raised for each stroke by a double-action steam cylinder and the energy delivered to the workpiece is supplied by the velocity and weight of the ram and attached upper die driven downward by steam pressure. The energy delivered during each stroke can be varied.

• **stock**
• A general term used to refer to a supply of metal in any form or shape and also to an individual piece of metal that is formed, forged, or machined to make parts.
• **stop**
• A device for positioning stock or parts in a die.
• **straightening**
• A finishing operation for correcting misalignment in a forging or between various sections of a forging.
• **strain**
• The unit of change in the size or shape of a body due to force, in reference to its original size or shape.
• **strain aging**
• The changes in ductility, hardness, yield point, and tensile strength that occur when a metal or alloy that has been cold worked is stored for some time. In steel, strain aging is characterized by a loss of ductility and a corresponding increase in hardness, yield point, and tensile strength.
• **strain hardening**
• An increase in hardness and strength caused by plastic deformation at temperatures below the recrystallization range. Also known as work hardening.
• **strain-hardening coefficient**
• See strain-hardening exponent .
• **strain-hardening exponent**
• The value *n* in the relationship = $K\ _n$, where is the true stress; is the true strain; and *K*, which is called the strength coefficient, is equal to the true stress at a true strain of 1.0. The strain-hardening exponent, also called *n*-value, is equal to the slope of the true stress/true strain curve up to maximum load, when plotted on log-log coordinates. The *n*-value relates to the ability of a sheet material to be stretched in metalworking operations. The higher the *n*-value, the better the formability (stretchability).
• **strain-rate sensitivity (*m*-value)**
• The increase in stress ( ) needed to cause a certain increase in plastic strain rate ( ) at a given level of plastic strain ( ) and a given temperature (*T*).
• **stress**
• The intensity of the internally distributed forces or components of forces that resist a change in the volume or shape of a material that is or has been subjected to external forces. Stress is expressed in force per unit area. Stress can be normal (tension or compression) or shear.
• **stress raisers**
• Design features (such as sharp corners) or mechanical defects (such as notches) that act to intensify the stress at these locations.
• **stress-strain curve**
• See stress-strain diagram .
• **stress-strain diagram**
• A graph in which corresponding values of stress and strain from a tension, compression, or torsion test are plotted against each other. Values of stress are usually plotted vertically (ordinates or *y*-axis) and values of strain horizontally (abscissas or *x*-axis). Also known as deformation curve and stress-strain curve.
• **stretcher leveling**
• The leveling of a piece of sheet metal (that is, removing warp and distortion) by gripping it at both ends and subjecting it to a stress higher than its yield strength.
• **stretcher straightening**
• A process for straightening rod, tubing, and shapes by the application of tension at the ends of the stock. The products are elongated a definite amount to remove warpage.
• **stretcher strains**
• Elongated markings that appear on the surface of some sheet materials when deformed just past the yield point. These markings lie approximately parallel to the direction of maximum shear stress and are the result of localized yielding. See also Lüders lines .
• **stretch former**
• (1) A machine used to perform stretch forming operations. (2) A device adaptable to a conventional press for accomplishing stretch forming.

• **stretch forming**
• The shaping of a sheet or part, usually of uniform cross section, by first applying suitable tension or stretch and then wrapping it around a die of the desired shape.
• **stretching**
• The extension of the surface of a sheet in all directions. In stretching, the flange of the flat blank is securely clamped. Deformation is restricted to the area initially within the die. The stretching limit is the onset of metal failure.
• **striking surface**
• Those areas on the faces of a set of dies that are designed to meet when the upper die and lower die are brought together. The striking surface helps protect impressions from impact shock and aids in maintaining longer die life.
• **strip**
• A flat-rolled metal product of some maximum thickness and width arbitrarily dependent on the type of metal; narrower than sheet .
• **stripper**
• A plate designed to remove, or strip, sheet metal stock from the punching members during the withdrawal cycle. Strippers are also used to guide small precision punches in close-tolerance dies, to guide scrap away from dies, and to assist in the cutting action. Strippers are made in two types: fixed and movable.
• **stripper punch**
• A punch that serves as the top or bottom of the die cavity and later moves farther into the die to eject the part or compact. See also ejector rod and knockout .
• **stroke (up or down)**
• The vertical movement of a ram during half of the cycle, from the full open to the full closed position or vice versa.
• **sub-sow block (die holder)**
• A block used as an adapter in order to permit the use of forging dies that otherwise would not have sufficient height to be used in the particular unit or to permit the use of dies in a unit with different shank sizes.
• **superplasticity**
• The ability of certain metals to develop extremely high tensile elongations at elevated temperatures and under controlled rates of deformation.
• **support plate**
• A plate that supports a draw ring or draw plate. it also serves as a spacer.
• **swage**
• (1) The operation of reducing or changing the cross-section area of stock by the fast impact of revolving dies. (2) The tapering of bar, rod, wire, or tubing by forging, hammering, or squeezing; reducing a section by progressively tapering lengthwise until the entire section attains the smaller dimension of the taper.
• **Swift cup test**
• A simulative test in which circular blanks of various diameter are clamped in a die ring and deep drawn into a cup by a flat-bottomed cylindrical punch. The ratio of the largest blank diameter that can be drawn successfully to the cup diameter is known as the limiting drawing ratio (LDR) or deformation limit.

• **T**
• **tandem die**
• Same as follow die .
• **tandem mill**
• A rolling mill consisting of two or more stands arranged so that the metal being processed travels in a straight line from stand to stand. In continuous rolling, the various stands are synchronized so that the strip can be rolled in all stands simultaneously. Contrast with single-stand mill .
• **tangent bending**
• The forming of one or more identical bends having parallel axes by wiping sheet metal around one or more radius dies in a single operation. The sheet, which may have side flanges, is clamped against the radius die and then made to conform to the radius die by pressure from a rocker-plate die that moves along the periphery of the radius die. See also wiper forming (wiping) .

- **tangent modulus**
- The slope of the stress-strain curve at any specified stress or strain. See also modulus of elasticity .
- **template (templet)**
- A gage or pattern made in a die department, usually from sheet steel; used to check dimensions on forgings and as an aid in sinking die impressions in order to correct dimensions.
- **tensile strength**
- In tensile testing, the ratio of maximum load to original cross-sectional area. Also known as ultimate strength. Compare with yield strength .
- **tensile stress**
- A stress that causes two parts of an elastic body, on either side of a typical stress plane, to pull apart. Contrast with compressive stress .
- **tension**
- The force or load that produces elongation.
- **thermal-mechanical treatment**
- See thermomechanical working .
- **thermomechanical working**
- A general term covering a variety of processes combining controlled thermal and deformation treatments to obtain synergistic effects, such as improvement in strength without loss of toughness. Same as thermal-mechanical treatment.
- **three-point bending**
- The bending of a piece of metal or a structural member in which the object is placed across two supports and force is applied between and in opposition to them. See V-bend die .
- **throw**
- The distance from the centerline of the crankshaft or main shaft to the centerline of the crankpin or eccentric in crack or eccentric presses. Equal to one-half of the stroke. See also crank press and eccentric press .
- **toggle press**
- **A** mechanical press in which the slide is actuated by one or more toggle links or mechanisms.
- **tong hold**
- The portion of a forging billet, usually on one end, that is gripped by the operator's tongs. It is removed from the part at the end of the forging operation. Common to drop hammer and presstype forging.
- **tooling marks**
- Indications imparted to the surface of the forged part from dies containing surface imperfections or dies on which some repair work has been done. These marks are usually slight rises or depressions in the metal.
- **torsion**
- A twisting deformation of a solid or tubular body about an axis in which lines that were initially parallel to the axis become helices.
- **torsional stress**
- The shear stress on a transverse cross section resulting from a twisting action.
- **total elongation**
- The total amount of permanent extension of a test piece broken in a tensile test usually expressed as a percentage over a fixed gage length. See also elongation, percent .
- **trimmer**
- The dies used to remove the flash or excess stock from a forging.
- **trimmer blade**
- The portion of the trimmers through which a forging is pushed to shear off the flash.
- **trimmer die**
- The punch press die used for trimming flash from a forging.
- **trimmer punch**
- The upper portion of the trimmer that contacts the forging and pushes it through the trimmer blades; the lower end of the trimmer punch is generally shaped to fit the surface of the forging against which it pushes.
- **trimmers**
- The combination of trimmer punch, trimmer blades, and perhaps, trimmer shoe used to remove

flash from a forging.
• **trimming**
• The mechanical shearing of flash or excess material from a forging with a trimmer in a trim press; can be done hot or cold.
• **trimming press**
• A power press suitable for trimming flash from forgings.
• **triple-action press**
• A mechanical or hydraulic press having three slides with three motions properly synchronized for triple-action drawing, redrawing, and forming. Usually, two slides--the blankholder slide and the plunger--are located above and a lower slide is located within the bed of the press. See also hydraulic press , mechanical press , and slide .
• **tryout**
• Preparatory run to check or test equipment, lubricant, stock, tools, or methods prior to a production run. Production tryout is run with tools previously approved; new die tryout is run with new tools not previously approved.
• **tube stock**
• A semifinished tube suitable for subsequent reduction and finishing.
• **two-high mill**
• A type of rolling mill in which only two rolls, the working rolls, are contained in a single housing. Compare with four-high mill and cluster mill .
• **U**
• **U-bend die**
• A die, commonly used in press-brake forming, that is machined horizontally with a square or rectangular cross-sectional opening that provides two edges over which metal is drawn into a channel shape.
• **ultimate strength**
• The maximum stress (tensile, compressive, or shear) a material can sustain without fracture; determined by dividing maximum load by the original cross-sectional area of the specimen. Also known as nominal strength or maximum strength.
• **underfill**
• A portion of a forging that has insufficient metal to give it the true shape of the impression.
• **upset**
• The localized increase in cross-sectional area of a workpiece or weldment resulting from the application of pressure during mechanical fabrication or welding.
• **upset forging**
• A forging obtained by upset of a suitable length of bar, billet or bloom.
• **upsetter**
• A horizontal mechanical press used to make parts from bar stock or tubing by upset forging , piercing, bending, or otherwise forming in dies. Also known as a header.
• **upsetting**
• The working of metal so that the cross-sectional area of a portion or all of the stock is increased. See also heading.

• **V**
• **V-bend die**
• A die commonly used in press-brake forming, usually machined with a triangular cross-sectional opening to provide two edges as fulcrums for accomplishing three-point bending .
• **vent**
• A small hole in a punch or die for admitting air to avoid suction holding or for relieving pockets of trapped air that would prevent die closure or action.
• **vent mark**
• A small protrusion resulting from the entrance of metal into die vent holes.

• **W**
• **warm working**
• Deformation at elevated temperatures below the recrystallization temperature. The flow stress and rate of strain hardening are reduced with increasing temperature; therefore, lower forces are

required than in cold working. See also cold working and hot working .
• **web** • A relatively flat, thin portion of a forging that effects an interconnection between ribs and bosses; a panel or wall that is generally parallel to the forging plane. See also rib .
• **wiper forming (wiping)**
• Method of curving sheet metal sections or tubing over a form block or die in which this form block is rotated relative to a wiper block or slide block.
• **wire**
• A thin, flexible, continuous length of metal, usually of circular cross section and usually produced by drawing through a die.
• **wire drawing**
• Reducing the cross section of wire by pulling it through a die.
• **wire rod**
• Hot-rolled coiled stock that is to be cold drawn into wire.
• **work hardening**
• See strain hardening .
• **workability**
• See formability .
• **wrap forming**
• See stretch forming .
• **wrinkling**
• A wavy condition obtained in deep drawing of sheet metal, in the area of the metal between the edge of the flange and the draw radius. Wrinkling may also occur in other forming operations when unbalanced compressive forces are set up.

• **Y**
• **yield**
• Evidence of plastic deformation in structural materials. Also known as plastic flow or creep.
• **yield point**
• The first stress in a material, usually less than the maximum attainable stress, at which an increase in strain occurs without an increase in stress. Only certain metals--those which exhibit a localized, heterogeneous type of transition from elastic to plastic deformation--produce a yield point. If there is a decrease in stress after yielding, a distinction can be made between upper and lower yield points. The load at which a sudden drop in the flow curve occurs is called the upper yield point. The constant load shown on the flow curve is the lower yield point.
• **yield strength**
• The stress at which a material exhibits a specified deviation from proportionality of stress and strain. An offset of 0.2% is used for many metals. Compare with tensile strength.
• **yield stress**
• The stress level of highly ductile materials, such as structural steels, at which large strains take place without further increase in stress.
• **Young's modulus**
• A term used synonymously with modulus of elasticity. The ratio of tensile or compressive stresses to the resulting strain.

## References

1. K. Osakada. History of Plasticity and Metal Forming Analysis. ICTP 2008 (The 9th International Conference on Technology of Plasticity), pp.22-43.
2. W. Hosford, R.M. Caddell. Metal forming: Mechanics and Metallurgy. Cambridge University Press, New York, 2007, p. 312.
3. ASM Handbook. Volume 14, Forming and Forging, ASM International, 2004, p.2110.
4. ASM Handbook. Volume 14A, Metalworking: Bulk Forming. ASM International, 2005, p.816.
5. ASM Handbook. Volume 14B, Metalworking: Sheet Forming, ASM International, 2006, p.1040.

**ТЕХНОЛОГИЧЕСКИЕ ПРОЦЕССЫ ОБЪЕМНОЙ ШТАМПОВКИ**
(термины и определения на английском языке):
Учебное пособие по практической части курса

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**FORMING AND FORGING TECHNOLOGIES**
(terms and definitions in English)
Study guide for the implementation of the practical part of the course

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