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Hot metal droplets capture with centrifugal method

Улавливание горячих брызг металла центробежным методом

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Abstract. Weld spatter properties and ways of spatter formation were analyzed in the article. It was deter-mined that solidified spatter can be considered as an active agent in environment pollution due to high dispersion, and there is a mass excess comparing with spatter spray. Hot metal droplets were used to track the flow of jets. The major part of spatter being under solidification has the size of 200 micron by dispersion and can be picked up by modern exhaust devices. The time of droplets solidification reaching heat content magnitudes able to cause firing of cloth filters in dust-tripping devices was determined during the experiment. There was elicited 100 % capture performance of hot metal droplets being under solidification in a uniflow cyclone CP-2500 (ЦП-2500) using marking tracers from particulate matter determination method.

Аннотация. В статье проанализирован механизм образования и свойства брызг металла при сварке. Определено, что застывшие брызги металла в силу высокой дисперсности являются активным загрязнителем окружающей природной среды и превышают по массе сварочный аэрозоль. Большая часть остывающих капель металла по дисперсному составу имеют размер от 200 мкм и улавливаются современными вытяжными устройствами. В эксперименте установлено время остывания капель до величин теплосодержания, способных вызывать загорание тканевых фильтров пылеочистных установок. Установлена 100 % эффективность задержки остывающих капель в прямоточном циклоне ЦП-2500 (CP-2500).

Introduction

Weld spatter is considered to be unfavorable welding wire consumption with low efficiency. It is accompanied by welding of spatters to the material that is used. It is claimed as a safety hazard, which may cause burns and fires. Several authors describe aspects and behavior of welding spatter in studies [1–4].

Also due to high dispersion solidified metal spatter can be considered as an active agent in environment pollution. Because the mass of spatter exceeds the mass of welding aerosol in hundred times. However, the part of metal spatters is not taken into account in estimation of hazardous emissions during welding.

Unfavorable consequences of metal sputtering make difference due to the use of air purifiers made on the basis of nonwoven polymer fabric during welding. Air-intake devices (AID) of filter and ventilation units (FVU) are arranged at a distance of 0.25–0.40 m from welding arc to ensure efficient performance. They take not less than 75 % of welding spray and a part of molten metal spatter flying to the surface of air-intake devices.

Group of scientists carried out CFD simulations and researches of the flow of uniflow cyclone [5]. They verified with the experimental results for different velocities profiles.

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Authors from Korea Institute of Energy Research proceed numerical calculation with ANSYS Fluent CFD program to predict pressure loss and internal flow of uniflow cyclone at the plant of coal gasification [6].

Recently, other researchers studied flow pattern in adapted swirl generator and compared with standard design of uniflow cyclone. The description of investigated effect is approved by CFD simulation of the flow profile within the vane channels. They were evaluated by PIV measurements [7].

Other authors studied the effect of flow streams on particle movement in a uniflow cyclone separator. In simulation of movement solid particles in a flow field was used the Eulerian–Lagrangian approach [8].

The studies of hot gas filtration and implementation of different sorbents are described in several articles [9–11]. There was described a problem of explosion and burnings.

Scientists from KTH Royal Institute of Technology, Sweden held investigations of metal droplets on a polished cross section of slag samples by using a Scanning Electron Microscopy (SEM). They have classified all metal droplets in slag samples depending on their morphology. [12]

A number of experiments [13] were carried out to obtain the data on sizes, flying distance and temperature of molten metal spatter.

During the experiments was found out the following:

- Cooling metal droplets have spherical form.
- Solid droplets of sputtering metal with the temperature of + 400 ^{0}C make it possible to melt totally polyester filter fabric. Droplets with the temperature of + 600 ^{0}C contribute to coking of welded edges.
- The major part of solid metal droplets (up to 85 %) with final temperature 400 ÷ 600 ^{0}C fly to the distance of up to one meter from a welding joint. The maximum dispersion accounts to 2 meters.
- Initial velocity of drops flying-off from welding blowpipes is equal to 8 ÷ 14 m/s.
- Average velocity of free settling of drops with the mass of 7.8 g is equal to 4.4 m/s.
- The major mass – 95 % of drops get cold up to the temperature below radiance (less than 600 ^{0}C) within less than 0.25 s.
- Sizes of droplets are their fall diameters, which make it possible to classify them as dust, and are enough to be picked up by exhaust devices and be travelled along ducts.

The aim of this article is characterize the experimental capturing of hot metal droplets in swirling flow. According to the previous articles on metal sputtering [14–18] the fact and the reason are identified, but they do not define initial velocity and rate decreasing of temperature including the context of drops and fractures. To achieve the aim was set a task to make several experiments with highlighted particles.

Methods and Results

Such dry inertial separators as settling chambers, louvered dust collectors and cyclones with centrifugal force are applied in industry to slow down motion of hot solid metal drops produced during welding or cutting processes. [19]

Industrial developers of such devices use the term – spark arrestors. But it is not accessible in the case of noncombustible metal droplets. According to the Russian State Standard GOST 53323-2009 “Flame arresters and spark catchers. General specifications. Testing methods” it is stated that a dry-type spark catcher is a device to be placed on exhaust manifolds of different vehicles and power units, which ensures that spatter of combustibles should be caught and extinguished, which is normally formed by furnace or internal combusting engine operation. A cooling droplet is not combustible. Its extinguishing is considered as heat power decrease up to the define values. That do not cause fire-hazardous materials to catch fire during any contact. This decrease is possible when heat is transferred to air and materials of dust collectors.

Cooling droplets in settling chambers and louvered dust collectors change their direction of rectilinear motion striking surfaces of dust collectors. In the case of cyclones with centrifugal force cooling solid droplets move keeping more complicates and longer tracks and strike cyclone walls.

Change of direction when it comes to rectilinear motion of cooling solid droplets was used by different manufactures in the following units: type “JETCLEAN” ZAO (CJSC) Konsar (Russia) – labyrinth filter, type FILTERCUBE Company TEKA (Germany) – cooper louvered filter, filter and ventilation unit of ZAO (CJSC) SovPlym (Russia) PMSF and others – settling chamber. Centrifugal motion of cooling droplets is used in uniflow cyclone – a spark arrestor "SPARKSHIELD" of the ventilation company "Plymovent Group" (Netherlands) and in cyclones – spark catcher TSG-1 ÷ 20 (ЦГ-1 ÷ 20) ZAO (CJSC) SPACE-MOTOR (Russia). The mechanism of collecting solid metal droplets during welding or cutting in these devices was not described. The effectiveness of temperature decreasing of droplets was not determined.

The experimental research of catching heated droplets of solid metal using centrifugal method was carried out with experimental unit on the basis of uniflow cyclone CP-2500 (ЦП-2500).

The uniflow cyclone CP-2500 (ЦП-2500) that is produced by SovPlym Ltd. since 2003 according to the Specifications (TU) 346-009-05159840-2003. At the entry of the cyclone the air flow is whirled by axial air mover. Large particles of dust are dropped out to the cyclone walls under centrifugal force and are headed to a dust chamber through a side connector. Cylindrical louvered grills inside the cyclone and inertial dust chamber additionally increase separation process and ensure high effectiveness of the cyclone [20]. The overall dust collecting effectiveness of the cyclone is around for 90.4 %.

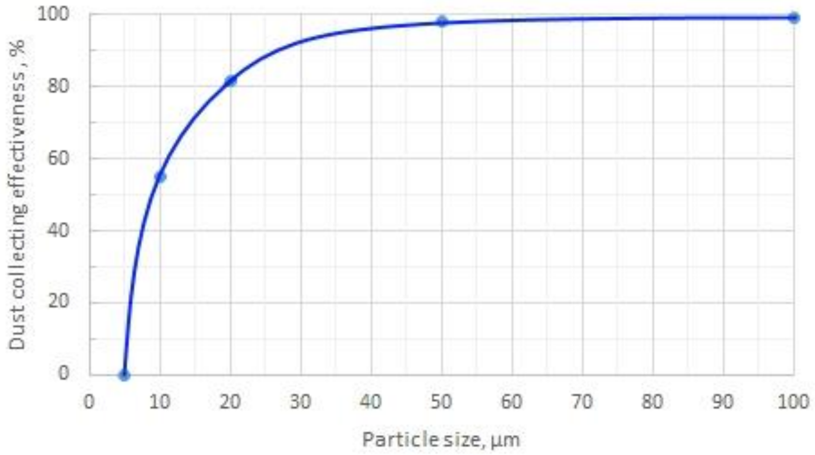
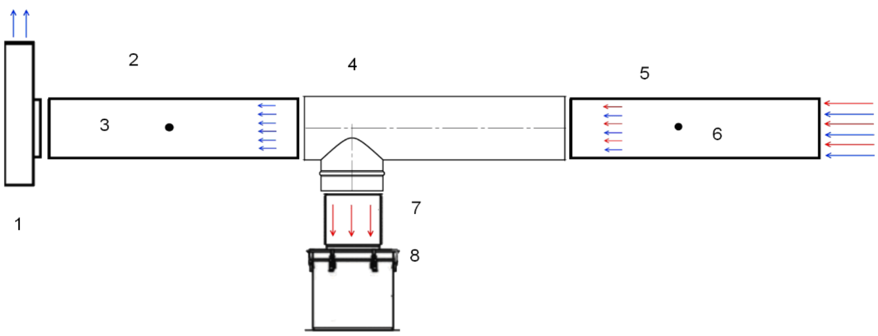


Figure 1. Dust collecting effectiveness in fractures

An estimated time for dust particles staying in the cyclone is equal to 0.15 sec [21, 22].



Picture 2. Scheme of the experimental unit

1 – a fan featured by frequency control TEF-600,

2 and 5, 7 – translucent ducts,

3 and 6 – tracers to mark hot particles,

4 – cyclone CP-2500 (ЦП-2500),

8 – dust collector.

← heated metal droplets,

← welding spray.

Metal spatter was formed due to semi-automatic welding. It was used building-up technique in the protective medium: mixture of argon and carbon dioxide; 8mm diameter wire "Св08Г3С". Current is 120 A, voltage is 19.8 V. Speed of wire feed is 6.6 m/min. Adapters with filters of the type "АФА-ВП-20" were used as tracers to mark hot metal droplets. They were placed in the section center of translucent air ducts. The material “АФА” is based on perchlorovinyl fibre. Perchlorovinyl fibre is not flammable. Decomposition temperature for perchlorovinyl is equal to 130–140 ^{0}C.

Hydraulic resistance of the system was 1645 Pa. It was measured in air ducts before and after cyclone at airflow rate 3400 m^3/h. Parameters were measured using a differential manometer DT-8890 with a receiver of total and static pressure Pitot tube. Results and estimations are shown in the Table.

Table 1.

№	Pressure sensing point	Pd, Pa	Pv, Pa	Ps, Pa	V, m/s	Q, m3/h	∆Pv, Pa
1	before cyclone work	220	530	750	19.1	3382	1645
2	after cyclone work	225	2175	2400	19.3	3420	

Recording was held during experiment where hot droplets flow through translucent air ducts. Continuous light emission in the translucent air duct was seen at the entry of the cyclone, and single tracks of hot droplets were seen before the dust chamber. As a result there were no luminous tracks at the exit of the cyclone.

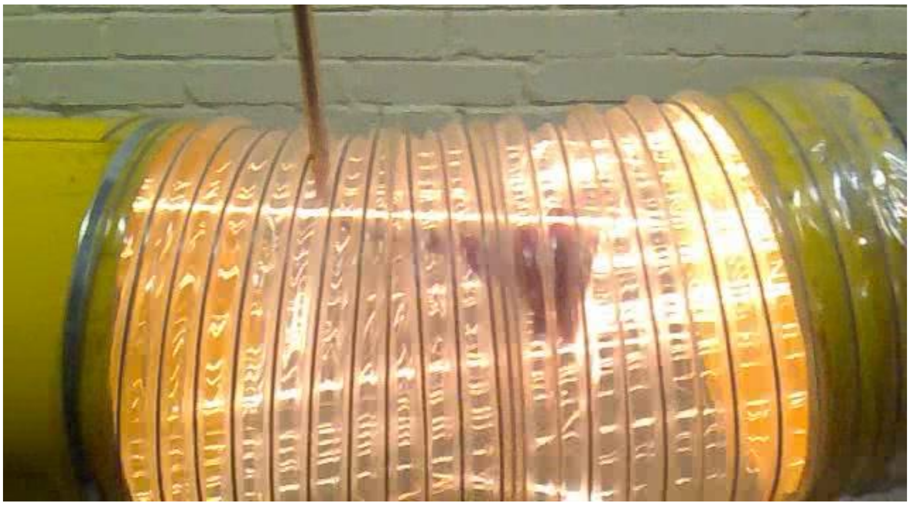
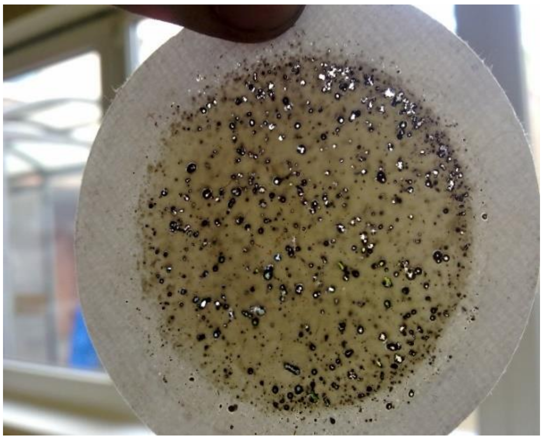


Figure 3. Tracks of hot metal droplets at the entry of the cyclone

The distance to the welding arc is 2 meters. A marking tracer – dust receiving adapter is arranged in the center of the air duct. Tracers to mark hot metal droplets were used to identify whether they appeared or not in the flow before and after cyclone work.

before cyclone work **after cyclone work**



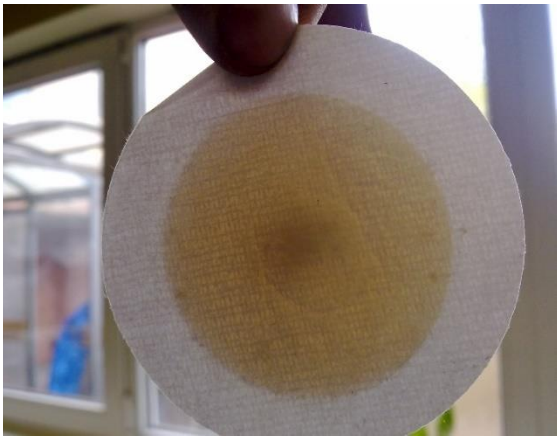
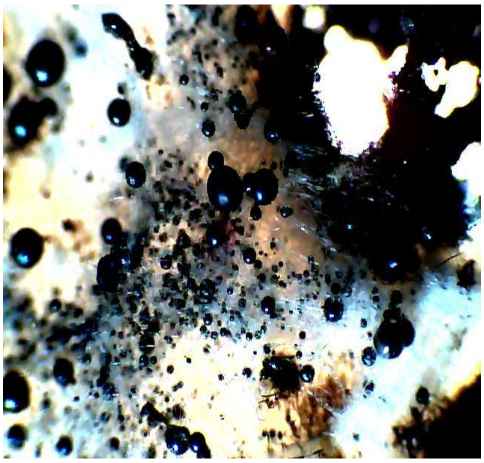


Figure 4. Marking tracers before and after cyclone work (1:1)



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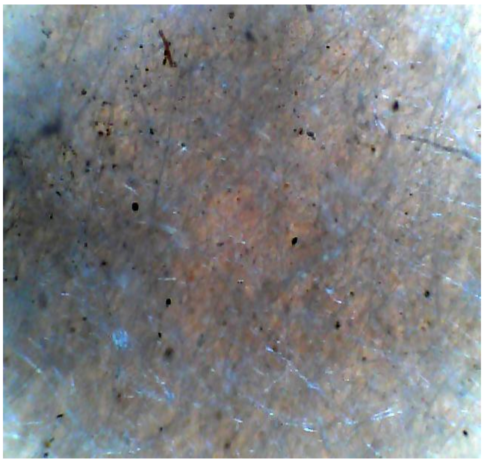

1:10

Picture 5. Solidified droplets of metal spatter, 50μm on filter fiber

Perchlorovinyl fibre that was used as marking tracers, can be melted at the temperature of 130–140 ^{0}C. Droplets with the size of 50 μm in diameter and less, which were suspended of the fiber surface of the first marking tracer, had heat output, which was not enough for melting. Larger droplets went through, burnt in and made fiber charred and darkened. On the second marking tracer we can see single solidified droplets, which sizes are ten times less than were picked up by the first marking tracer. On the marker after the cyclone there were no burning droplets and going through the fiber particles.

During analysis of video snapshots was received additional information about motion of particles in the cyclone (CP) ЦП and motion of hot metal droplets. In the flow entering of device can be already observed the effect of air mover for circular whirled flows. It also can be seen how the air flow changes from rectilinear motion into circular before it enters the cyclone. When the spinning flow goes to the dust receiver single hot particles continue to move in a circular manner going on in the dust receiver. Then leave the traces of their motion to the bottom.

Discussion

Mechanism of metal spatter formation and its danger

Sputtering of liquid electrode metal is caused by gas-dynamic impact. It emerges when a bonding strip between a welding wire and a droplet is broken transferring to a molten pool. The pressure emerged is radially forwarded away from the point of disruption. When this occurs there is a possibility of liquid metal slopping in the area of both a bonding strip and an electrode tip. A liquid droplet rapidly solidifies when flying out of the arc zone. The initial temperature of the solid particle is about 1500 up to 1130 ^{0}C. [5, 6, 23, 24]

The coefficient of electrode metal loss during sputtering ψ is determined by the difference between the masses of metal consumed and metal weld. An actual value of ψ for covered electrodes may vary within the limits 5–20 %. In the case of stable welding processes when carbon dioxide gas with 2 mm diameter electrodes is used, the value ψ accounts for 5–8 % and does not exceed 15 %, and in the case of CO_2+Ar – 5–7 %. About 10–30 % of molten metal spatter formed while welding under average regime depending on physical welding conditions stick and is welded to working area of nozzles, current contact tips (CCT) being part of welding blowpipes, and detecting devices in welding machines and robots. The rest part – much minor droplets – (as drops in a liquid state and as solid spherical particle in a state of crystallization), fly away from a welding seam.

Metal spatter during crystallization has spherical form. Maximum size of spatter is a bit more than the diameter of welding wire, the minimum size may account for tenths or a hundredths of a millimeter. The major part of spatter in the case of stable welding processes can be attributed to the droplets of the size equal to 2/3 of the wire diameter. Depending on technological conditions of welding molten metal spatter can be classified as small (< 0.2 mm), medium (0.2–0.5 mm) and large (> 0.5 mm). [7–9]

The temperature of molten metal droplets (spatter) reaches to 250–500 °C in a second after a contact with the surface. Also temperature depends on the contact diameter of their interaction and the thickness of the metal being welded, and in a 6–7 seconds heat generation is almost equal to 0. [25]

Estimations according to Russian State Standard GOST (ГОСТ) 12.1.004-91 show that the molten metal droplet under crystallization with the size of 5-mm in diameter keeps the temperature of 852 ^{0}C in 1.1 seconds after its formation and may transfer 0.16 Joule of heat to the environment, and that is enough for major part of combustibles to ignite.

When horizontal welding the largest and heaviest droplets of molten metal are welded to the metal and stay on the manufactured object in the area of approximately 200 mm away from the welding seam. Metal droplets which are getting cold fly down during the process of vertical and overhead welding.

Flying droplets of the metal under crystallization appeared to be flying sparks of different radiance. Colors of various gradients like yellow and white or yellow and red indicate that the temperature of the steel, which is getting cold, is 1200–900 ^{0}C. A quenched spark of barely discernible dark brown color has the temperature of 550 degrees ^{0}C. This autoignition temperature of most combustibles is much higher than +70 ^{0}C, and it may cause first-degree burns of skin after the contact with the object heated within over 1 second. [26]

Due to high dispersion solidified metal spatter can be considered an active agent in environment pollution, and there is a mass excess comparing with spatter spray. The major part of spatter being under solidification has the size of 200 micron by dispersion and can be picked up by modern exhaust devices.

Conclusions

1. An experimental installation for research performance of hot metal drops catching was constructed from uniflow cyclone CP-2500 (ЦП-2500) with air swirl generator, inlet louvered grill and dust collecting tank.
2. Experiment was held with marking tracers from particulate matter determination method.
3. The video was recorded to track the flow of jets which were formed by hot metal droplets
4. Was demonstrated that the process to separate hot metal drops in the uniflow cyclone causes the temperature drop of flying droplets from 800 up to 130 ^{0}C and less. Particles get cold in the cycle within 0.15 sec which is less than cooling process when they are idle – 0.25 ÷ 0.5 sec.
5. Was demonstrated that CP-2500 (ЦП-2500) construction ensure that 100 % of fire-hazardous solid hot metal droplets are picked up.

Consequently, it was first described in the research an opportunity to catch hot metal droplets and avoid ignition of explosive dust.

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