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Use of anti-spatter substances in welding processes

Abstract: The article presents the course and results of tests involving the use of anti-spatter substances. The study determined the effect of the anti-spatter substance applied on the surface of workpieces on the quality and properties of welded joints as well as the effect of the anti-spatter substance applied on the welding torch elements on the active life of nozzles and contact tubes used in MIG/MAG welding and plasma cutting processes.

Keywords: welding, spatter formation, anti-spatter substances, MIG, MAG, plasma cutting

Introduction

The problem of spatter formation during welding works is very common and may be responsible for approximately 5-10% of losses in filler metals. Spatters adhering to welding torch elements necessitate the exchange of contact tubes and cleaning of the nozzles, which in turn decreases the efficiency of welding works. Frequent replacements of welding fixtures increases the costs of welding and cutting. Spatters accompany most welding processes. In MIG/MAG welding spatters are usually caused by the following factors:

- low current in relation to the diameter of electrode wire,
- overly low inductance of a welding circuit during short-circuit metal transfer,
- excessively long, exposed electrode wire,
- type of shielding gas,
- purity of the filler metal (presence of impurities in the form of oxides or other chemical substances) [1].

Spatter-caused impurities settling on welding torch elements can trigger the formation of imperfections such as gas pores, incomplete fusion or lack of penetration in the weld. Spatters accompanying welding processes adhere not only to welding torch elements but also to workpieces, thus deteriorating their aesthetics. This poses a basic technological challenge, e.g. during welding car body sheets. The primary remedy eliminating spatters both from the surface of workpieces as well as from welding torch elements consists in the use of anti-spatter substances. However, if used improperly such substances may contribute to the formation of imperfections in welded joints, e.g. lack of penetration, incomplete fusion and localised porosity. These imperfections are formed during the pre-weld preparation of workpieces as well as while applying the anti-spatter substance on the surface of workpieces when an excessive amount of such a substance enters the area of a weld groove. Classification societies often

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require the presentation of objective test results proving that the use of a given anti-spatter substance does not adversely affect the properties of welded joints.

Scope of tests

The tests involved the use of two types of anti-spatter substances, i.e. aerosol to be applied onto the surface of workpieces and aerosol to be used mainly on welding torch elements. The scope of tests related to the first stage of research was developed on the basis of standard PN-EN ISO 15614-1 [2] and included

- MAG (135) welding of butt joints in 10 mm thick S355J2+N steel,
- MAG welding of T-joints with a filler weld in 10 mm thick S355J2+N steel,
- NDT of all welded joints (visual and radiographic testing of butt joints and visual testing of T-joints),
- destructive testing of welded joints:
  - tensile tests, impact and bend tests as well as macroscopic tests and hardness measurements of butt joints,
  - fracture test of both T-joints as well as macroscopic tests and hardness measurements of a joint with a small amount of anti-spatter substance in the weld groove.

In the case of the anti-spatter substance used on welding torch elements the scope of tests included:

- MAG welding in S355 steel,
- MAG overlay welding in S355 steel,
- MIG welding in 6082, 7075 and 2017A aluminium alloys,
- manual plasma cutting in 12 mm thick S355 steel.

Prior to tests the anti-spatter substance was applied on a welding torch nozzle (both inside and outside) and on a contact tube following the instructions of a related manual. After several seconds the substance dried forming a white ceramic coating on the surface (Fig. 1).

In order to prevent the substance from entering a weld (imperfection risk), the electrode wire was pulled out and its tip covered with the anti-spatter substance was cut off. In doing so, great attention was paid not to damage the anti-spatter coating on the nozzle and on the contact tube. It was observed that the protective coating became hard due to heat emitted at the initial stage of welding. As a result, the durability of the coating increased.

The methodology of testing the anti-spatter substance involved comparing the condition of the welding torch contact tube without the anti-spatter protection and with anti-spatter coating, after MIG/MAG welding, MAG overlay welding and plasma cutting. The tests of the processes enumerated above were carried out for the same time and using the same parameters. The assessment included the amount of spatters and difficulty connected with their removal.

Testing anti-spatter substance applied on workpieces

Welding butt joints with butt weld

In the case of the anti-spatter substance applied on workpieces, joints were made using manual MAG welding. The whole course and range of tests was consistent with requirements related to the qualification of welding technologies presented in standard PN-EN ISO 15614-1. The first butt joint was prepared in accordance with Figure 2. Before welding the workpieces were coated with the anti-spatter substance. The anti-spatter application technique was the same as the one used in practice, i.e. the amount of the substance entering the weld groove was small (Fig. 3). The welding sequence was as presented in Figure 2.

Fig. 1. MAG welding torch tube with anti-spatter substance coating

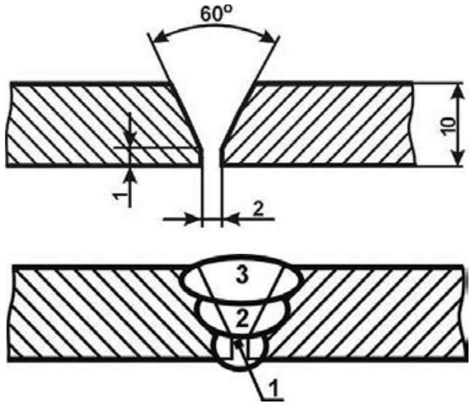

Fig. 2. Preparation of elements for welding and welding sequence

Fig. 3. Weld groove with small amount of anti-spatter substance after making tack welds

The visual testing conducted directly after welding showed that the joint represented the quality level B. The weld surface did not reveal any cracks or porosity. The radiographic tests did not disclose the presence of any welding imperfections. Figure 4 presents the weld radiogram and the macroscopic metallographic photograph of the joint made.

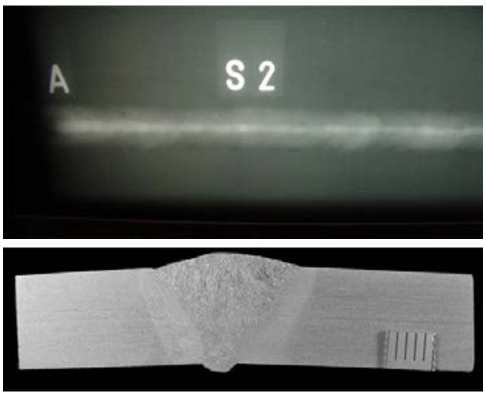

Fig. 4. Radiogram and macrostructure of the weld made with a small amount of the anti-spatter substance in the weld groove, quality level B according to PN-EN ISO 5817

Afterwards, the welded joint was sampled for test pieces for further destructive tests. Tensile tests bend tests, impact tests and hardness measurements were carried out following the requirements of standard PN-EN ISO 15614-1.

The tensile test results of two test pieces sampled from the same joint (549.2 MPa and 547.3 MPa) met the minimum tensile strength criterion (Rm ≥ 470 MPa). The bend tests of 4 test pieces revealed a bend angle of 180° for the bending mandrel diameter of 40 mm. The welds subjected to bending with both weld face and weld root tension contained no scratches or cracks. The impact tests carried out at -20°C revealed an average weld impact strength of 34.7 J and an average HAZ impact strength of 93.3 J. Therefore, the minimum impact strength criterion for S355J2+N steel amounting to 27 J at -20°C was fulfilled. The hardness measurements carried out in two lines of the welded joint section revealed the maximum HAZ hardness at approximately 200 HV, meeting the maximum hardness criterion of ≤380 HV.

Afterwards, a butt welded joint was made, on which the excessive amount of the anti-spatter substance was applied both on the sheet surface and in the weld groove area (Fig. 5). The welding process was conducted using the same parameters as in the case of the previous joint.

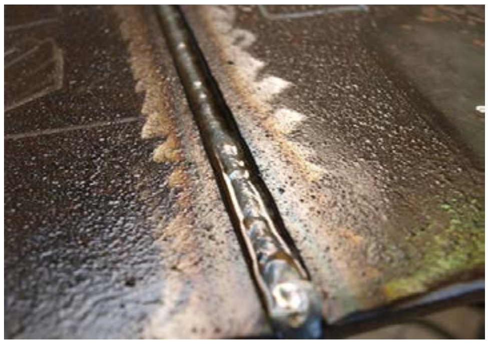

Fig. 5. Weld groove with excessive amount of anti-spatter substance after making a root run

During welding it was observed that even a significant amount of the anti-spatter substance applied did not impede the course of the process, i.e. no excessive spatter was formed and arc burning was stable. The visual tests carried out afterwards did not reveal the presence of pores on the weld surface. The radiographic tests did not reveal the presence of any gas

Fig. 6. Radiogram of the weld made with the excessive amount of anti-spatter substance in the weld groove, quality level B according to PN-EN ISO 5817

Fig. 7. Workpieces with a small amount of the anti-spatter substance in the interface

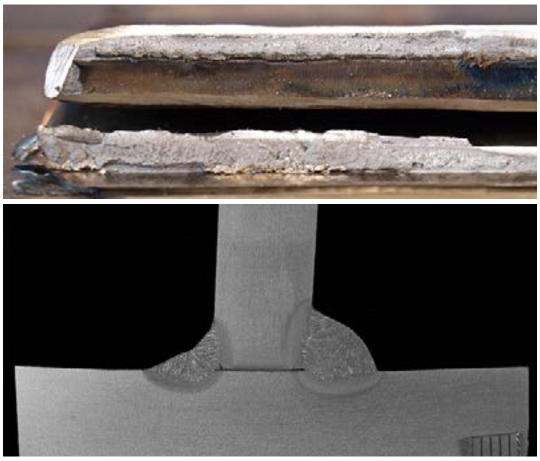

Fig. 8. Weld after the fracture test and the macrostructure of the joint made with the small amount of the anti-spatter substance in the interface

Fig. 9. Elements with the excessive amount of the anti-spatter substance applied in the joint interface

pores in the weld (Fig. 6). The joint represented the quality level B and in terms of quality did not differ from the one made previously.

Welding T-joints using a fillet weld

The testing methodology applied to T-joints with a fillet weld was identical as the one used for butt joints. The first joint was made with the same amount of the anti-spatter substance applied on the surface of elements to be joined as the one used in practice, which means that the amount of the substance entering the weld groove was small (Fig. 7). Before making the main fillet weld a seal weld was made on the other side of the joint. The seal weld presence tightened the restrictions of test conditions as it hindered the release of anti-spatter substance vapours through a gap in the interface. The seal weld was made prior to anti-spatter substance application.

During welding it was possible to observe stable arc burning, proper parent metal wetting and proper fusion into the web and flange material. No excessive spatter could be seen. The visual tests did not reveal any porosity on the weld face surface. The fracture tests and macroscopic metallographic tests revealed proper fusion into both walls of the joint, which represented the quality level B. Figure 8 presents the fracture test result and the joint macrostructure.

The hardness measurements were conducted following the requirements of a related standard concerning the qualification of technologies. The results revealed a HAZ hardness of approximately 350 HV, i.e. meeting the maximum permissible hardness criterion. Afterwards, a T-joint with a fillet weld was made. The excessive amount of the anti-spatter substance was applied both on the surface of sheets and in the interface of the elements (Fig. 9). Welding was carried out using the same parameters as in the case of the previous joint.

During welding with an excessive amount of the anti-spatter substance, it was observed that obtaining proper fusion was very difficult, as the anti-spatter substance layer constituted, in a way, a natural barrier preventing proper wetting of the edges to be joined. In order to determine whether the joint was made properly and if fusion into the walls of workpieces was appropriate, it was necessary to conduct a fracture test. The fillet weld was cut along the whole length and next fractured by an impact. The fracture test result and the macroscopic metallographic test result are presented in Figure 10.

The tests conducted confirmed what was observed during welding of a T-joint with a significant amount of the anti-spatter substance applied. Both the fracture test and macroscopic metallographic examination revealed the absence of fusion in the joint. However, the weld did not contain gas pores, which indicates that even such a significant amount of the anti-spatter substance as the one applied in the interface of workpieces can evaporate during welding and does not trigger the formation of gas pores. On the other hand, the absence of fusion disqualified the joint as failing to meet the quality level B requirements according to PN-EN ISO 5817. Proper fusion might have been obtained with greater welding linear energy but it had been assumed previously that joints should be made using similar parameters.

Testing anti-spatter substance applied on welding torch elements

MAG welding

Twelve millimetre thick S355J2 steel sheets were welded using the MAG method, a G3Si1 electrode wire with a diameter of 1.2 mm and CO_2 used as a shielding gas. The conditions of 2-minute and 5-minute long welding were selected in order to generate significant spatter (Fig. 11). The first stage involved testing the MAG welding influence on the condition of a nozzle and on a contact tube not protected with any anti-spatter substance. It was observed that welding torch elements were covered with many spatters difficult, yet possible, to remove (Fig. 12).

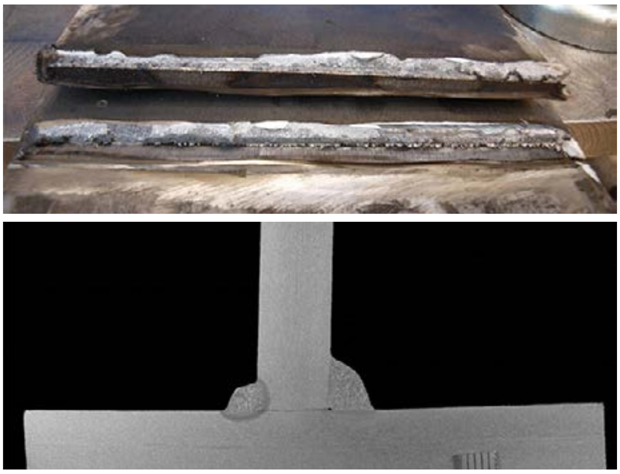

Fig. 10. Weld after the fracture test and the macrostructure of the joint made with the significant amount of the anti-spatter substance in the interface

Fig. 11. MAG welding in steel – visible significant spatter.

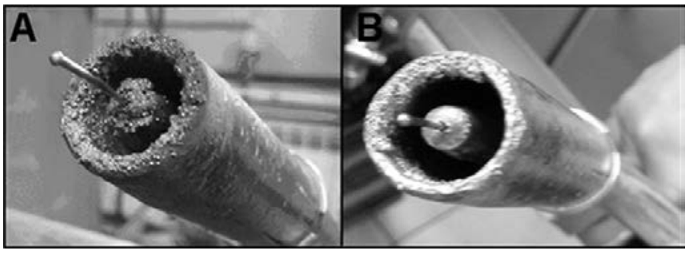

Fig. 12. Nozzle and contact tube without the anti-spatter substance. A- after 5-min long welding, B- after removing most spatters.

Fig. 13. Nozzle and contact tube with the anti-spatter coating after 5-minute long welding.

Afterwards, the nozzle and the contact tube were coated with the anti-spatter substance following the instructions provided on the anti-spatter substance container. After 2-minutes of welding, the nozzle and the contact tube were still free from spatters, yet 5 minutes of welding led to the appearance of spatters on the nozzle (Fig.13). Hitting the nozzle gently caused the spatters to fall off easily. After removing the spatters it was possible to observe the intact protective coating.

MAG overlay welding

Overlay welding was carried out automatically. The tests involved the use of pipes made of the following materials:

1. R35 steel, 150 mm in diameter; wall thickness of 8 mm,
2. 32HA steel, 150 mm in diameter; wall thickness of 10 mm.

Overlay welding involved the use of a G3Si1 electrode wire with a diameter of 1.2 mm and a shielding gas mixture of 82%Ar+ 18%CO_2 (PN EN ISO 14175 M21-ArC-18). The process lasted approximately 10 minutes and welding current reached as many as 300 A. Overlay welding was accompanied by the formation of significant spatters (Fig. 14).

Fig. 14. MAG overlay welding of pipes

During overlay welding, the nozzle and the contact tube not provided with the protective coating became covered with spatters, the removal of which was difficult (Fig.15). After applying the protective coating the nozzle and the contact tube remained free from spatters (Fig. 16).

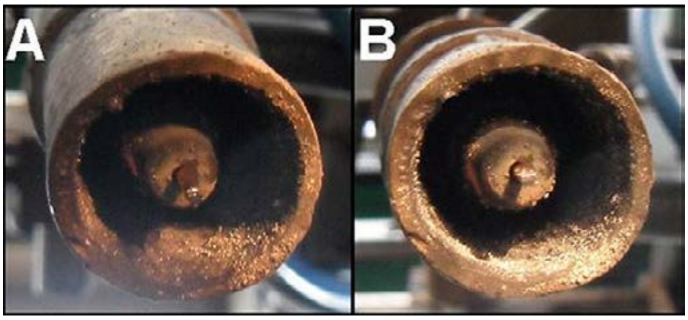

Fig. 15. Nozzle and contact tube after MAG overlay welding, without the anti-spatter coating. A- before cleaning, B- after spatter removal.

Fig. 16. Nozzle and contact tube coated with the anti-spatter substance, after MAG overlay welding (10 min).

MIG welding

MIG welding was carried out on 4 mm thick 6082 aluminium alloy sheets using an AlMg4.5MnCrZr (Al5087) electrode wire with diameters of 1.0 and 1.2 mm and argon as a shielding gas. Similarly to MAG overlay welding, the initial welding tests were carried out without the protective coating applied (Fig. 17).

Fig.17. Nozzle and contact tube after MIG welding (5 min), without the protective coating; visible spatters.

Afterwards, the anti-spatter substance was applied as in the case of MAG overlay welding (Fig. 18).

The welding process lasted 5 minutes for each type of sheet. The process went on smoothly and no spatters adhering to welding torch elements were observed (Fig. 19). This was due to a relatively low, if compared with steel, aluminium melting point of approximately 660°C.

Fig. 18. Nozzle and contact tube with the anti-spatter substance applied; view before welding

Fig. 19. Nozzle and contact tube with the anti-spatter substance applied, after MIG welding (5 min).

Plasma cutting

During plasma cutting plasma gas blows out molten cut metal, as a result of which significant spatters are formed (Fig. 20). This phenomenon is significantly more intense than in the case of MIG/MAG welding. A material being cut is blown out of a cut gap also in the direction of a welding torch, causing the contamination of the plasma nozzle elements.

The plasma cutting process was carried out for approximately 5 minutes using a manual plasma cutting machine. The tests involved the use of the same materials as in the case of MAG overlay welding, i.e. 12 mm thick S355J2 steel sheets. Initially, the anti-spatter substance was not applied, which led to the formation of spatters permanently adhering to the welding torch elements (Fig. 21).

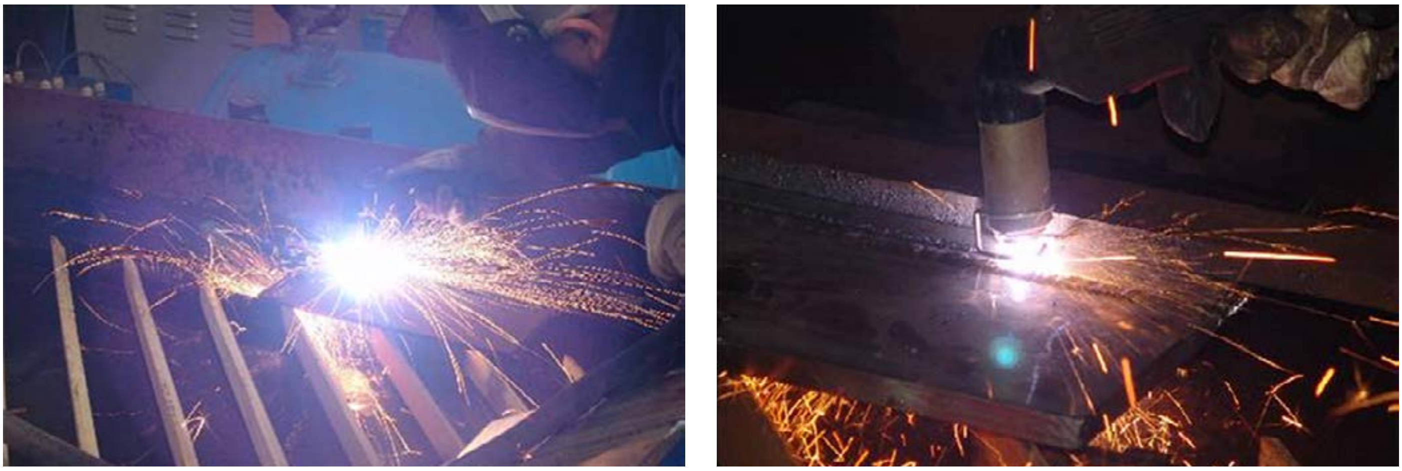

Fig.20. Manual plasma cutting process

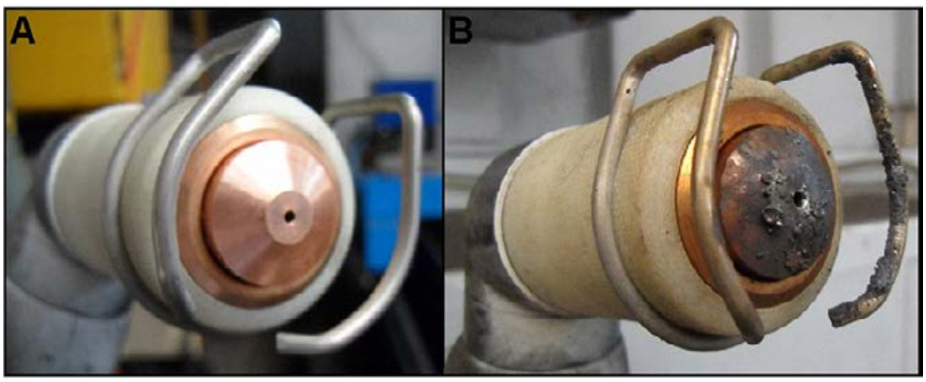

Fig. 21. Plasma nozzle, casing and guide without anti-spatter substance: A- before cutting, B- after cutting.

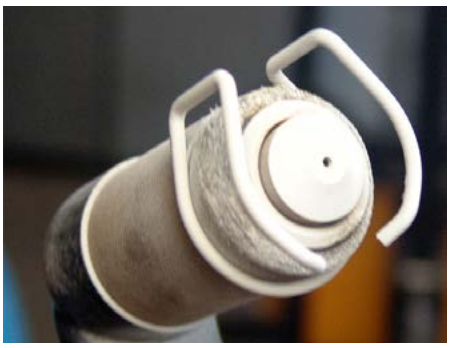

Fig. 22. Plasma nozzle, casing and guide with anti-spatter substance applied; view before plasma cutting

Next, a new nozzle and casing were provided with the anti-spatter substance as in the previous processes (Fig. 22).

Following plasma cutting, the torch elements were subjected to visual tests revealing the formation of easy-to-remove spatters adhering to the end of the nozzle (Fig. 23).

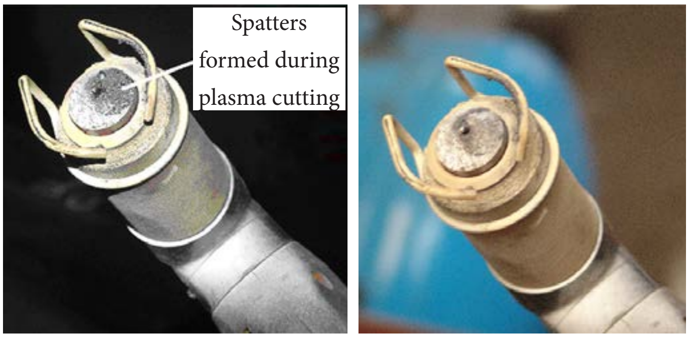

Fig. 23. Plasma nozzle and casing with anti-spatter substance applied; view after plasma cutting: A- nozzle with spatters, B- nozzle after removal of spatters

Summary

Butt joints and T-joints made in 10 mm thick S355J2 steel, protected by the anti-spatter substance applied on manually MAG welded workpieces meet welding technology qualification-related criteria specified in PN-EN ISO 15614-1. The anti-spatter substance can be successfully used for protecting workpieces and welding torch elements against the adhesion of spatters during welding. However, sufficient attention should be paid not to apply the excessive amount of this substance, particularly in the case of T-joints with a fillet weld, as this may impede obtaining proper fusion.

In the case of the anti-spatter substance applied on the welding torch elements it was observed that the substance significantly improved the quality of the aforementioned welding processes. These processes are often accompanied by the formation of spatters adhering to the nozzle and contact tube, destabilising welding works and resulting in the generation of welding imperfections. This necessitates carrying out additional procedures such as cleaning or exchanging nozzles or contact tubes, which increases the time consumption and the cost of works. One-time application of the anti-spatter substance on the welding torch elements provides excellent protection against the adhesion of impurities. The anti-spatter substance is easy to use; the protective coating is resistant to high temperatures and remains for a long time on surfaces where it has been applied.

Concluding remarks

1. The anti-spatter substance applied on workpieces before welding prevents the formation of porosity or gas pores in welds.
2. The butt and T-shaped joints made in 10 mm thick S355J2 steel protected with the anti-spatter substance and welded manually using the MAG method according to WPS meet the criteria related to the qualification of welding technologies referred to in PN-EN ISO 15614-1.
3. The limited but sufficient (spatter formation preventing) amount of anti-spatter substance applied in the weld groove or in the interface between workpieces does not affect the properties of welded joints.
4. If applied excessively in the interface between workpieces, the anti-spatter substance may impede obtaining proper fusion in the case of a T-joint using a fillet weld.
5. The application of the anti-spatter substance on the welding torch elements during such welding works as MAG welding or MAG overlay welding ensures the easy removal of spatters adhering to the nozzle and to the contact tube.
6. The use of the anti-spatter substance to protect the welding torch elements during MIG welding of aluminium alloys entirely protects the nozzle and the contact tube against the adhesion of spatters.
7. Always after applying the anti-spatter substance on the MIG/MAG welding torch elements the end of the electrode wire coated with the anti-spatter substance should be cut off in order to prevent the formation of welding imperfections.
8. The use of the anti-spatter substance on the plasma cutting torch elements provides

successful protection against the permanent adhesion of spatters.

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