

Article

Analysis of the structure and selected properties of welds obtained by the CMT and MAG method

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Abstract: The article presents an analysis of the Cold Metal Transfer (CMT) method, including the process, advantages and application of the method. The joints made with low energy CMT method and classic MAG method were also compared. The paper presents the results of non-destructive penetrant tests of welded joints made of steel in the S235JR grade. Microscopic observations were made using optical microscopy and the hardness was measured in accordance with PN-EN ISO 6507-1:2007. The test results confirmed that the CMT process allows for the production of high-quality joints and a narrow heat-affected zone compared to the classic MAG welding method, and also provides good mechanical properties and elimination of spatter.

Key words: CMT method; MAG method; penetration testing; hardness; spatter

Introduction

The CMT method, which is derived from MAG technology, was introduced by Fronius in 2005. Its introduction on the market gave new possibilities, previously unattainable for the classic MAG method. The main difference between CMT and the classic MAG method is much lower welding energy, which facilitates the joining of materials with significantly different melting temperatures, such as steel and aluminum, and also reduces the occurrence of welding deformations. In addition, this method is characterized by almost complete absence of spatters arising during the welding process. This allows additional finishing processes to be bypassed, which reduces costs and increases welding efficiency [1].

Characteristics of the CMT welding process

Cold Metal Transfer welding is a relatively new technology that partially separates electric arc transistors from the wire feed.

Despite the fact that the process involves shorting of the welding wire circuit to transfer the material, by controlling both the cyclic arc phase and the wire feed speed, sufficient energy can be obtained to melt both the base material and the additive material. After the short circuit, but before reaching the peak value of the short-circuit current, the moment of mechanical retraction of the wire occurs, which causes a temporary interruption of the welding circuit and detachment of the liquid metal droplets of the electrode and its transition to a metallic bath (pulling the droplet into the pool assisted by the surface tension of the liquid). Limiting the short-circuit current in such a way results in limiting the amount of heat introduced into the joint [2,3]. The detachment of the metal droplets occurs with a temporary increase in the electrodynamic force in the arc (increase in current intensity) interrupted by a change in the direction of wire feed, resulting from the increase in the distance of the guide rollers located in the welding clamp. A classic droplet transition controlled by an increase in current (in short circuit or pulse), and thus an electrodynamic force in an arc, usually requires a higher value of current (than in CMT) to ensure the breakaway of droplet of the melted additive material [4÷6].

The basic CMT operating mode (Fig. 1) is characterized by the arc burning phase, during which a droplet forms at the end of the electrode wire and a weld pool is created in parallel. At the set time, the wire is moved forward to make contact with the weld pool, causing a short circuit. At this time, however, the arc control system limits the natural increase in short-circuit current. During this phase, droplet transfer is

initiated, and the current is significantly reduced (compared to a classic short circuit). After a certain time, the electrode wire is retracted and the liquid metal bridge breaks mechanically between the end of the electrode and the weld pool. Then the arc is reignited and the cycle repeats. The process is unique because not only the transport of liquid metal is controlled by the forward and backward movement of the electrode, but also the electrical properties, as a result of which the material passes at low voltage [4,5].

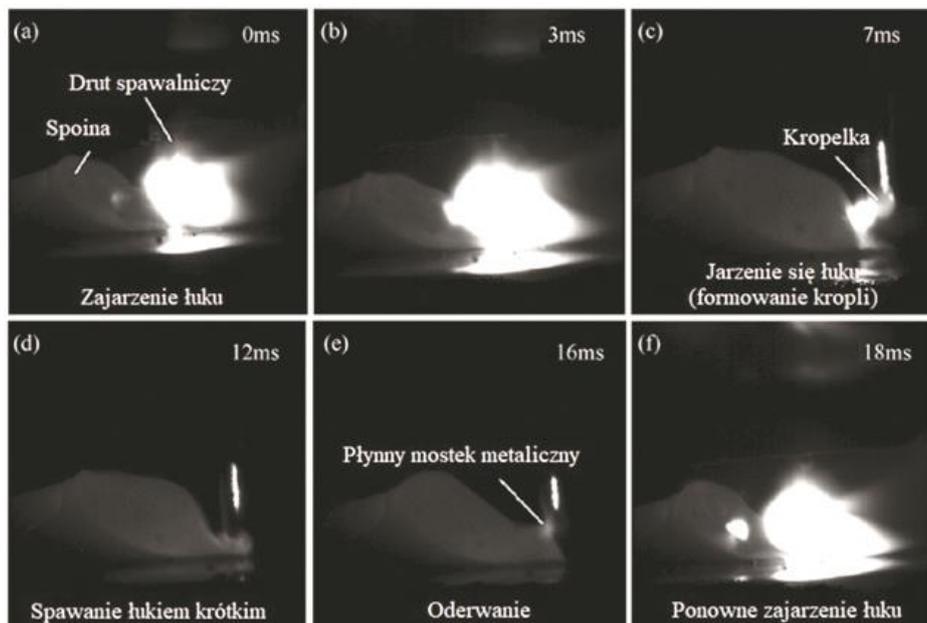


Fig. 1. Phases of the metal transport process in the CMT method [1,7]

In the CMT process, the wire feed is primarily a process parameter and directly affects the final result. The control system constantly controls the actual value of the speed at which the wire is fed and retracted in the feedback control loop. By the action of forces from the surface tension in the liquid metal pool, it is possible to detach the droplet regardless of the welding wire withdrawal process. All these features show that CMT is an innovative method in the field of welding processes. It allows to make welds or perform braze welding with almost no spatter (Fig. 2), even with extremely large welding angles [4,5].

CMT welding is characterized by reduced pollutant emissions (Fig. 3). Studies have shown that the concentration of impurities generated during the CMT process is much lower than during welding with the use of MAG method. Nearly 90% less copper vapor and 63% less zinc were detected when welding these materials (e.g., copper alloys and galvanized sheets) than in traditional welding technologies. Therefore, work with the use of CMT has less negative impact on the human body and the environment [7].

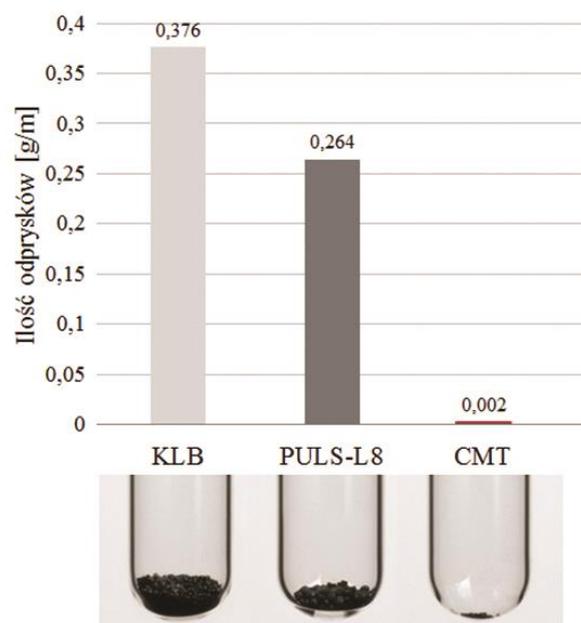


Fig. 2. Comparison of the amount of spatter generated during the welding process [7]

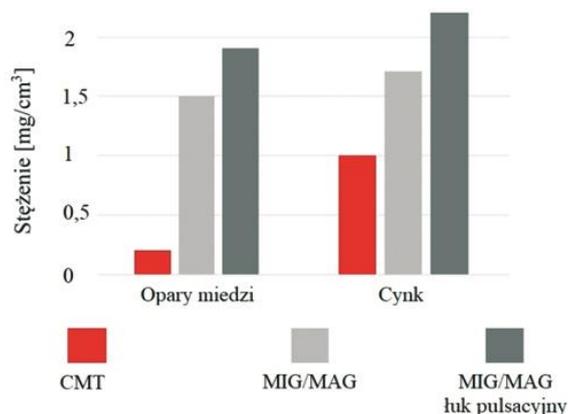


Fig. 3. Difference in pollutant emission in the MIG/MAG and CMT method [7]

The CMT method is mainly used for [8]:

- welding thin sheets, e.g. aluminum and its alloys, steel (e.g. galvanized steel, structural steels, HSLA steels, stainless steels);
- braze welding without spatters;
- welding nickel-based alloys, titanium alloys and copper alloys;
- welding aluminum with galvanized steel.

A new function of the CMT process is the CMT Pin/Print developed by Fronius (Fig. 4). CMT Pin is a proven welding process that allows surfacing pins with a height many times greater than their diameter on the outer surface of metals [8,9]. This is a form of additive machining (three-dimensional printing by welding).

This process consists of surfacing short metal pins onto a metallic substrate, the ends of which may have different shapes (Fig. 5).

To a large extent, the way a droplet is carried in an electric arc depends on the current density of the glowing arc. During gas-shielded welding, using a $\varnothing 1.0$ mm wire, the critical current density is approx. 200 A/mm². Above this limit, spray transfer occurs, while below, dip-globular transfer. The higher the current, the smaller the droplet will be [11,12].

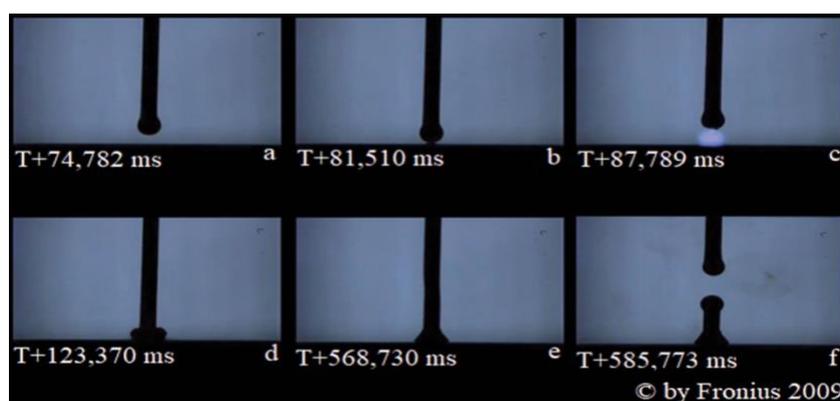


Fig. 4. CMT Pin process a) preparation for the process, b) application of the wire to the welded surface, c) arc ignition and wire heating, d) application of liquid metal to the substrate, e) cooling and shaping of the pin, f) detaching the wire from the resulting pin [10]

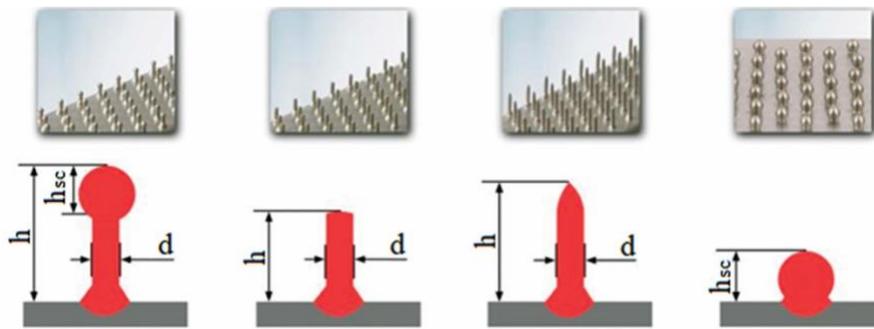


Fig. 5. From the left; CMT Pin, cylindrical CMT Pin, of spades CMT Pin, CMT Pin [10]

In the traditional dip-transfer welding method, the wire is pulled out uniformly even after being shorted with the base material. Then, the welding current increases, and a short-circuit begins, which is needed to re-ignite the arc. The short-circuit current value is not controlled. This causes an increase in the heat introduced into the welded material and the occurrence of spatters [1,3].

Material and research methodology

The material for the tests were samples with a thickness of 2 mm, made of S235JR grade steel 80 x 150 mm, which were butt-welded using the CMT and MAG method (Table I).

To carry out penetration tests, materials from Diffu-Therm (Table II) were used and levels of indications acceptance were analyzed (Table III).

Table I. Parameters of welding process

	CMT Method	MAG Method
Welding current intensity [A]	200	60
Arc voltage [V]	19.4	18
Wire feed [m/min]	12.9	3.5
Shielding gas	M21 Ar+15÷20% CO ₂	M21 Ar+15÷20% CO ₂
Electrode wire diameter [mm]	∅ 1.0	∅ 1.0
Electrode wire grade	ER70S-6	ER70S-6

Table II. Specification sheet for a set of materials used in penetration testing

Materials used in penetration testing			
Type of measure used	Penetrant red BDR	Remover BRE – S, containing acetone	Developer BEA containing 2-propanol
Identifications according to the manufacturer	Ch. Nr 2114	Ch. Nr 7011	Ch. Nr 2317
Type of packaging	Aerosol	Aerosol	Aerosol
Manufacturer	Diffu-Therm	Diffu-Therm	Diffu-Therm
Standard used	PN-EN 571	PN-EN 571	PN-EN 571

Table III. Levels of acceptance of indications according to PN-EN ISO 23277:2015-05

Type of indication	Level of acceptance		
	1	2	3
Linear indications l = length of the indication [mm]	l ≤ 2	1 ≤ 4	1 ≤ 8
Non-linear indications d = dimension of the main axis [mm]	d ≤ 4	d ≤ 6	d ≤ 8

The hardness test was performed using the Vickers method at a load of 10 N for 15 s, on the MICROHARDNESS TESTER FM-700 by FUTURE-TECH. The measurements were carried out in accordance with PN-EN ISO 6507-1: 2007. Metallic materials - Vickers hardness test - Part 1: Test method.

Research results

In addition to visual tests, penetration tests were carried out to verify the occurrence of open surface incompatibilities. Visible longitudinal linear indications on the welds (Fig. 6) are apparent indications whose occurrence is caused by a change in the height of the joint profile, a fault in the vicinity of the fusion line.

Observing the surface of the butt welds (Fig. 7) from the face and ridge, even at low magnification, one can observe a large difference in the width of the heat affected zone in favor of the CMT variety. This is due to the difference in the amount of heat introduced into the material during the welding process.

Comparing the structure of the materials that were combined using the CMT method (Fig. 8) and the MAG method (Fig. 9), there was no radical difference. Subtle changes in favor of the CMT variety concern several areas. The grain growth in HAZ and the HAZ width of the joint made using the MAG method are larger than welds made using the CMT method. The microstructure of joints made by CMT and MAG in native material was ferritic with martensite precipitations at grain boundaries, while in HAZ and weld, bainitic and martensitic structure was observed.

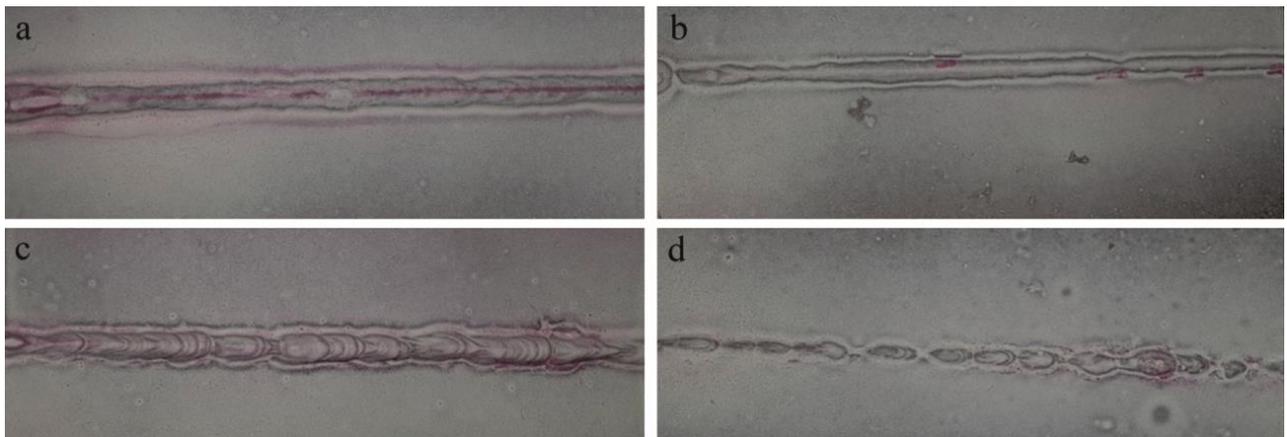


Fig. 6. CMT and MAG samples after penetration tests: a) CMT butt weld face, b) CMT butt welds ridge, c) MAG butt welds, d) MAG butt welds ridge

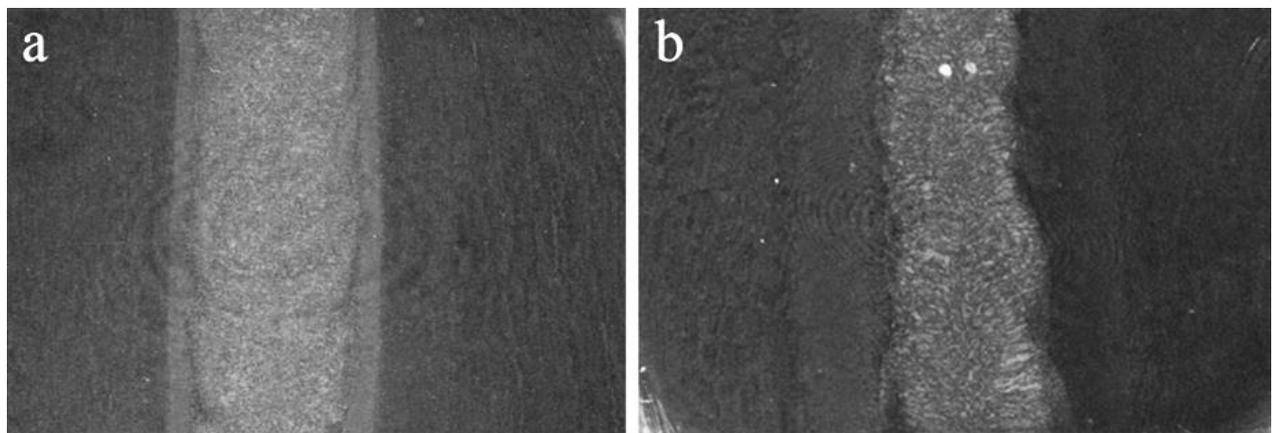


Fig. 7. Comparison of butt welds made with a) CMT and b) MAG methods

A significant difference in favor of the CMT method was the amount of registered spatter. In the joint made using the CMT method no spatter permanently associated with the surface of the material was noted. In the case of a joint made using the MAG method (Fig. 6c), the spatter is quite intense, associated with the joint surface, and its removal requires additional technological operation. The results of hardness measurements indicate that the hardness of the weld in both joint variants is comparable and has a value of approx. 220 HV. The HAZ registered a hardness higher by about 15 HV in the CMT joint, which may be the result of a smaller grain growth and a higher cooling rate of the joint (Fig. 10). The measuring points for hardness tests were in a straight line through the cross-section of the sample. For each sample area, i.e. native material, heat affected zone and weld, 5 measurements were made, their average value was presented on the graph.

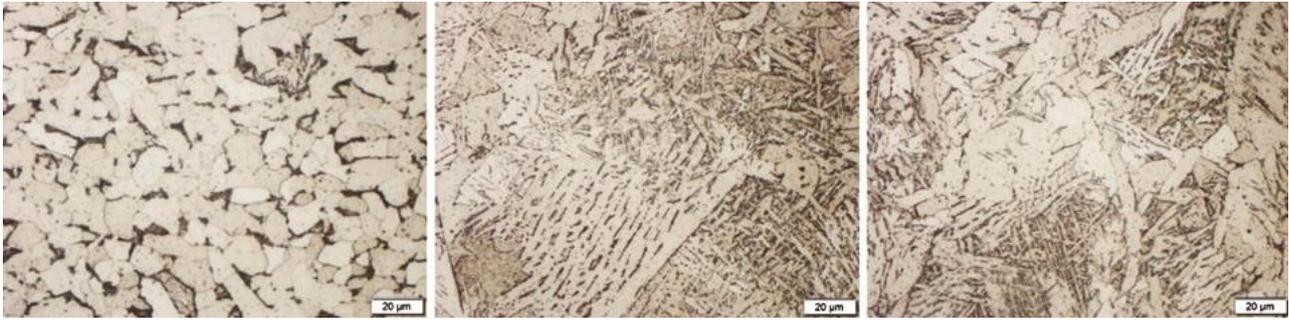


Fig. 8. From the left, the base material, the heat affected zone and the butt weld made using the CMT method (magn. 1000x)

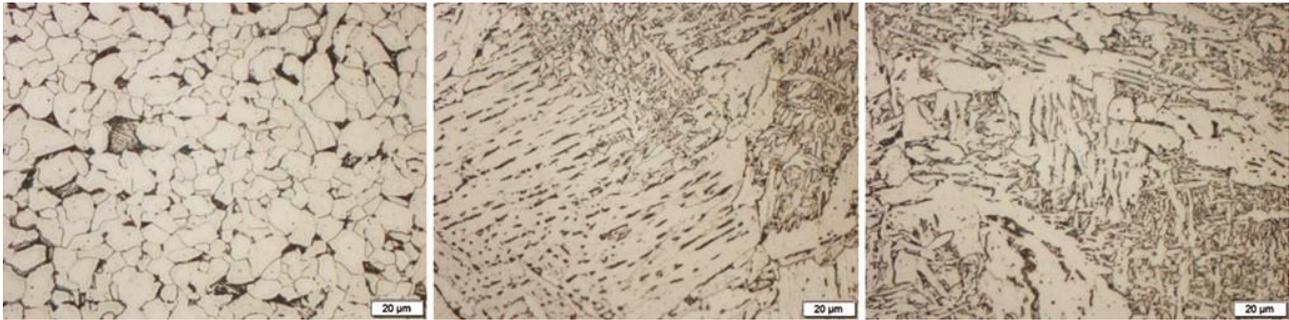


Fig. 9. From the left, the parent material, the heat affected zone and the butt weld made using the MAG method (magn. 1000x)

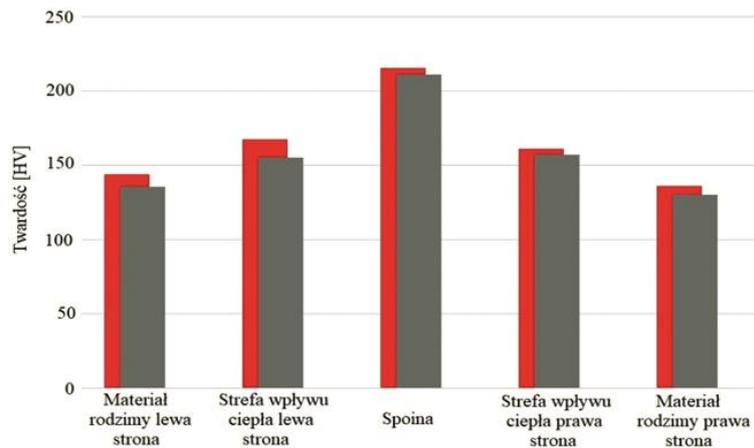


Fig. 10. Average value of HV hardness in individual butt joint zones made with the CMT method (black bars) with the MAG method (gray bars)

Discussion of the research results

Along with the launch of the Cold Metal Transfer method, numerous studies have been undertaken to determine the mechanical properties of welds. The results of the tests and literature data indicate that welds produced using the CMT method show better mechanical properties than welds made using the MAG method.

Penetration tests show that there are no indications on the weld's surface in joints made using the CMT method. Visible longitudinal lines of the penetrant are apparent indications that result from the fault along the fusion line. Metallographic studies indicate that the structure of the heat and weld zone made using the CMT method is characterized by smaller grains. In addition, it can be seen that spatter occurs on samples made using the MAG method (Fig. 6). After analyzing the research results [12], it can be concluded that the experimental and literature results overlap. The width of the heat affected zone is significantly greater in MAG joints. In studies [13,14], welds produced by the classical welding method in shielding gases are characterized by higher hardness, compared to welds obtained by the CMT method. What is worth noting in the conducted tests, large grains were separated in the heat affected zone and MAG fillet weld, which were distinguished by greater hardness than the hardness tested in samples obtained by the CMT method. The cross-section of samples obtained using the MAG method has a less regular shape, steel samples have been

deformed due to the influence of high temperature, after using the CMT method, the welds are symmetrical and are of good quality without excessive deformation of the native material. On the other hand, analysis of literature data proves that the shape of welds made using CMT and MAG methods practically does not differ, welds are high and smooth [15].

Conclusions

Based on the analysis of research results, the following conclusions were made:

- samples of joints obtained using the CMT and MAG method showed similar hardness, both in the heat affected zone and in the weld. After conducting metallographic tests, it was found that large grains were separated in the heat affected zone of the MAG fillet joint, the hardness of which exceeded the hardness obtained by the CMT method;
- penetration tests showed that welds made using the CMT method do not show discontinuities, while welds obtained using the MAG method have small indications, which, however, do not exceed the scope of the standard;
- CMT is a non-spatter method, in contrast to the MAG method, which has a positive effect on the costs associated with surface treatment of joints;
- the CMT method slightly affects the width of the heat affected zone compared to the MAG method;
- the classic MAG method ensures greater penetration depth, with the same electrode wire feed as in the CMT method.

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