micro-jet cooling; MIG welding; steel welding structure

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ADVANTAGES OF NEW MICRO-JET WELDING TECHNOLOGY ON WELD MICROSTRUCTURE CONTROL

Summary. An innovative apparatus to welding process with micro-jet cooling of the weld made it possible to carry out technological tests, which have proved theoretical considerations about this problem. This project gives real opportunities for professional development in the field of welding with controlling the parameters of weld structure. These tests have proved that the new micro-jet technology has the potential for growth. It may be great achievement of welding technology in order to increase weld metal strength. The new technology with micro-jet cooling may have many practical applications in many fields, for example such as in the transport industry or to repair damaged metal elements. The advantages of the new device over the traditional system are the ability to control the structure of the weld, the weld mechanical performance increases and improve the quality of welded joints.

ZALETY NOWEJ TECHNOLOGII SPAWANIA MIKROJETOWEGO DOTYCZĄCE KONTROLI MIKROSTRUKTURY SPOINY

Streszczenie. W artykule przedstawiono innowacyjną technologię spawania z wykorzystaniem chłodzenia mikrojetowego dla połączeń spawanych konstrukcji samochodowych. Przedstawiono rozważania teoretyczne i kierunki rozwoju oraz wyniki przeprowadzonych prób technologicznych. Wykazano, że ta innowacyjna technologia jako pierwsza na świecie daje realne możliwości kontrolowania parametrów struktury spoiny w trakcie realizacji procesu spawalniczego. W przyszłości będzie możliwe uzyskanie określonej struktury spoiny bez dodatkowej obróbki, co znacznie skróci czas przygotowania wyrobów, a także poprawi jakość spoiny np. przez wzrost wytrzymałości. Nowa technologia mikrojetowa może mieć dużo praktycznych zastosowań w wielu dziedzinach, takich jak przemysł transportowy, lub może być wykorzystana do naprawy uszkodzonych elementów metalowych w tym wałów maszynowych. Zaletami nowego urządzenia w porównaniu z systemem tradycyjnym są możliwość sterowania strukturą spoiny, polepszenie parametrów mechanicznych spoiny i poprawa jakości złącz spawanych.

1. INTRODUCTION

In order to qualify for weld joints certain criteria must be fulfilled. Mostly these are the strength criteria which ensure the safety and durability of welded structure while operating. These are usually the requirements for welded joint strength but the minimum value of impact and resistance of weld metal deposit (WMD) are mainly given. The value of these quantities is dependent on many factors (e.g. method of welding, filler, technology). These factors influence over chemical composition and the structure of weld metal deposit and then it is reflected in the strength parameters and plastic properties of weld metal deposit. In the process of welding steel structures, the best properties are achieved in so called low-oxygen welding process (about 400 ppm) which gives the optimal weld metal deposit structure and a high content of desirable phase i.e. fine-grained of acicular ferrite (AF). The higher content of AF promotes the better plastic properties of weld metal deposit. Unfortunately, there are some restrictions which result from welding technology (actually applied) which as a result do not give a big content of ferrite AF in weld metal. Moreover, it seems that it is impossible to increase amount of ferrite AF in practice by applying the current technologies.

In this article is presented an apparatus to steel sheet welding where an innovative welding method with micro-jet cooling of the weld metal has been applied. It allows to control the weld metal structure and finally obtain a high content of AF inside of it. It could be used in automotive industry and service [1÷7].

2. THE WELD METAL COOLING IDEA

The idea of this work is that steel sheet are welded and additionally a micro-jet injector is used in order to cool weld metal. It allows to control precisely the weld structure and what follows the strength properties. A diagram of the welding process with micro-jet accessory is shown in the figure 1.

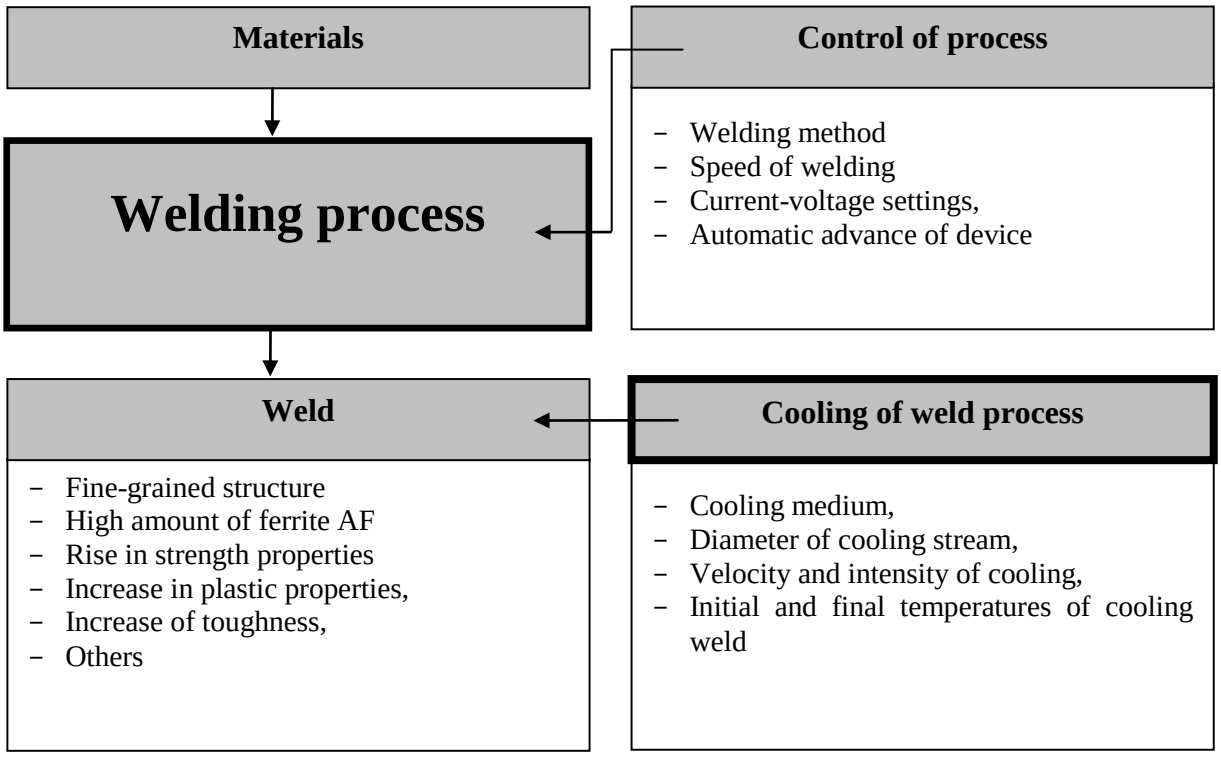

Fig. 1. A diagram of the welding process with weld metal cooling
Rys. 1. Proces spawania z wykorzystaniem chłodzenia mikrojetowego

In this process, weld structure is under control because surface of weld is quickly cooled by micro-streams of cooling (i.e. any liquid or gas). In that case, argon and water were chosen as cooling fluid. Argon is characterized as not having oxidizing potential. Water was chosen as a comparative medium in order to check whether or not additional rise in concentration of oxygen and hydrogen in weld would be observed after using it as a cooling liquid. Micro-streams of liquid are generated by micro-jet accessory [8÷10].

The applications of micro-jet accessory in welding process have been studied where as steel sheet were chosen low-alloy steel and low-carbon steel. In traditional welding the stages of formation of metallographic weld electrode structure are listed below (fig. 2):

a) while continual cooling of austenite, coarse-grained ferrite is first formed on the grain boundary,
b) next, plated ferrite is formed, it's superficial is oriented almost perpendicular to interior of the grains of "ex" austenite,
c) finally, fine-grained ferrite is formed inside of the grains,
d) at low temperatures, relatively a small quantity of austenite may be transformed into bainite and martensite,
e) not large quantity of austenite may remain in metallographic structure (so-called remained austenite).

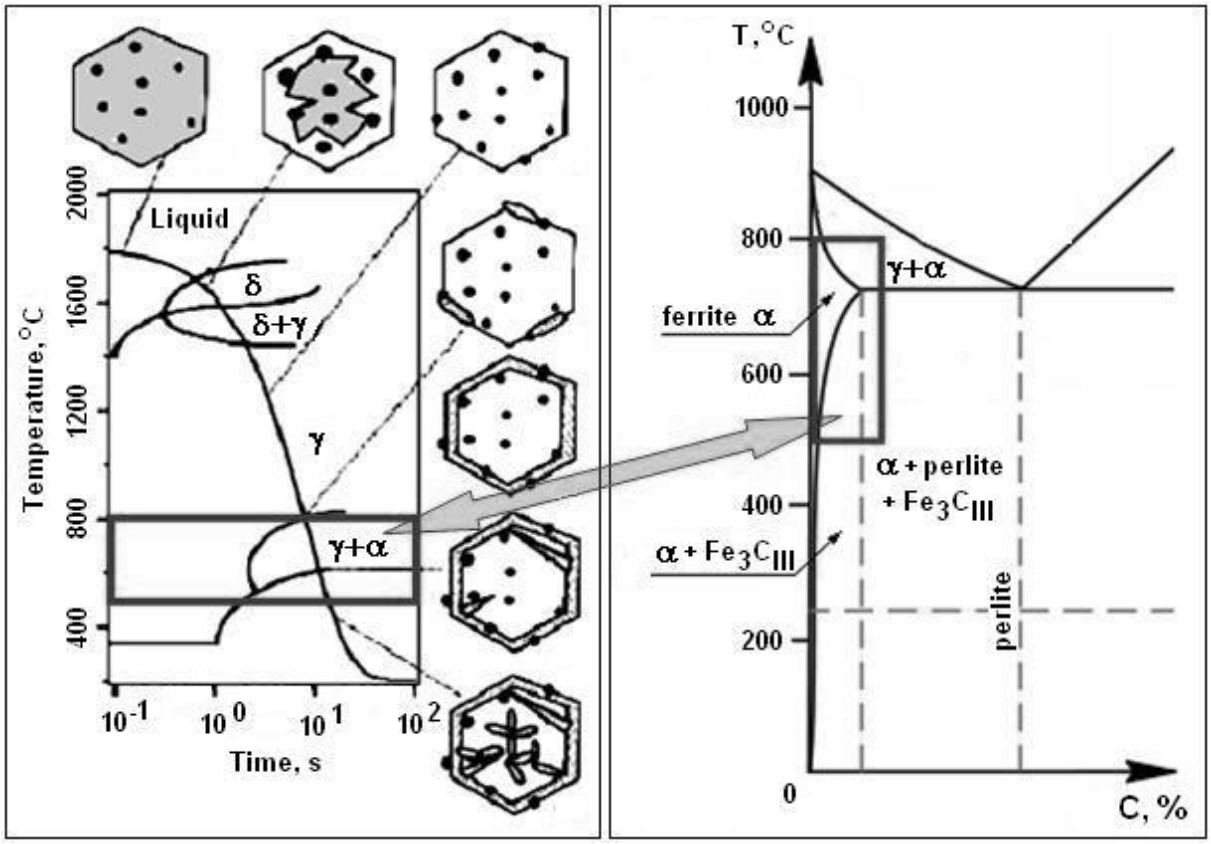

Fig. 2. Cooling TTT curve of electrode weld metal with reference to Fe-C diagram, areas where weld metal cooling is done are clearly marked [based on 11]

Rys. 2. Krzywa chłodzenia TTT dla elektrod w odniesieniu do wykresu Fe-C, z zaznaczeniem obszaru dodatkowego chłodzenia [na podstawie 11]

In figure 2 are marked areas where the process of weld metal cooling is done. It may be noticed that this process takes place in the range temperatures of about 800 ºC to 500 ºC. The marked content of carbon in the weld metal results from the chemical content of additional material, which was applied to welding.

The metallographic structure of the low-carbon and low-alloy weld metal consists mainly of three morphologic ferrite forms (fig.2):

- coarse-grained ferrite marked as GBF (grain boundary ferrite),
- site plate ferrite, marked as SPF (primary ferrite),
- fine-grained ferrite, marked as AF (acicular ferrite).

The metallographic studies, have confirmed the information given above. It is important that a bigger ferrite AF content of weld was observed for those weld metals which were prepared using the micro-jet injector (cooling process). Figure 3a shows the low-alloy metallographic structure of the weld metal where ferrite GBF and ferrite SPF are in large quantity (the weld metal was made without micro-jet cooling). Figure 3b shows the low-alloy metallographic structure of the weld metal where ferrite AF is in large quantity (the weld metal was made with micro-jet cooling).

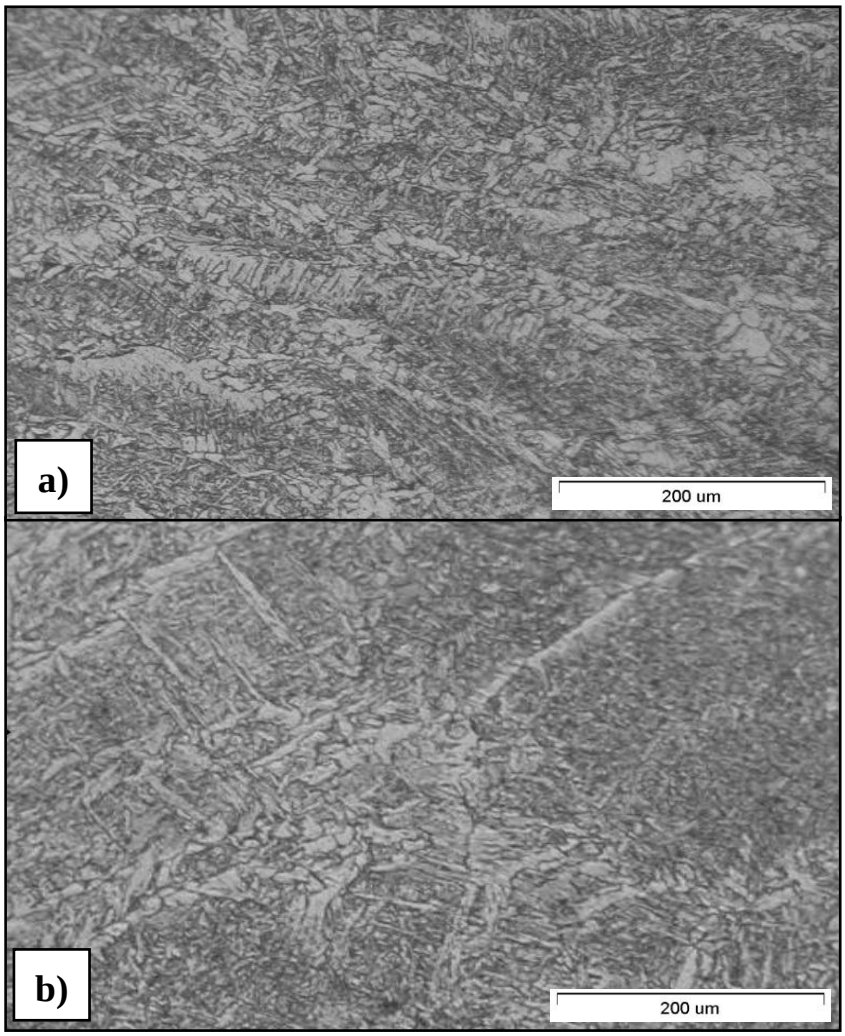

Fig. 3. The metallographic structures of the weld metal made: a) without cooling; b) with micro-jet cooling
Rys. 3. Struktura metalograficzna uzyskanych złącz spawanych: a) bez chłodzenia mikrojetowego, b) z dodatkowym chłodzeniem mikrojetowym

As regards to impact resistance, fine-grained AF is without doubt the most favorable phase. A positive influence of large quantities of fine-grained ferrite over impact resistance of weld metal electrode is unambiguously described in specialist literature, but opinions about the optimal conditions of forming that favorable phase of ferrite have been not standardized yet. Moreover, it is predicted that the methods of AF quantities control (for example by using low-oxygen processes or presence of non-metallic inclusions as nucleation initiators of AF) are nearing the end of theirs.

The basic hypothesis about the process of forming AF relies upon the proper cooling speed. On the basis of it, new technology has been worked up, where the welding process (in high temperatures in the range 800 ºC – 500 ºC) and the same the weld metal deposit is precisely controlled. It is possible to control over transformation of austenite to AF on condition that cooling speed is suitably chosen and regulated. The more amount of AF, promotes the mechanical properties of welded joint. The process of AF formation is difficult because of the unfavorable structures (martensite and bainite), which are formed simultaneously. Practical application of the micro-jet accessory in welding causes of increasing quantities of AF in the weld metal deposit. Thanks to this unique and innovative method of heating and cooling is possible to control over the weld metal deposit structure. The accelerated conditions of cooling process have the influence over the transformation of austenite to the most favorable phase i.e. AF. The innovative micro-jet accessory may have practical applications in different welding processes like: MIG, MAG, TIG, laser-beam fusion welding, EB welding plasma-arc welding, first of all in the automated and robotic processes. The innovative welding apparatus is being applied in MIG method [12÷18].

3. APPARATUS FOR WELDING WITH MICRO-JET COOLING

Welding technology with micro-jet injector is an automatic process where welding head with micro-jet moves thanks to a special carriage.

The essential element of that apparatus is welding equipment with welding head. It moves automatically and it's linear velocity may be regulated. Welding head is interconnected with micro-jet accessory, which has possibility of regulating the most important geometrical parameters of device (distance of micro-jet from the weld metal deposit and welding head, glacing angle micro-streams over the weld metal deposit). Moreover, the micro-jet accessory enables a welder to regulate intensity of cooling which has influence over the structure of the metal weld deposit. A distance welding head from cooling micro-jet is very important parameter because it has influence on the optimal structure of the weld metal deposit. It is possible to regulate that parameter in the range of about 25 mm to 65 mm on the test stand. The higher value of the distance lower is the temperature at the beginning of the weld metal deposit.

Welding apparatus with weld metal deposit cooling using the micro-jet accessory is shown in the figure 4. It's construction enables the welder to head-on weld of metal plate and facing by welding. The test stand consists of two basic elements, namely the semi-automatic welder and the welding bench with fittings. Basic data on welding bench are given in table 1.

Table 1

Basic date on welding bench

Parameters	**Value, mm**
Height	1400
Width	600
Length	1600
Maximum length of metal plate	1190
Maximum thickness of metal plate	20
Minimum width of metal plate	120

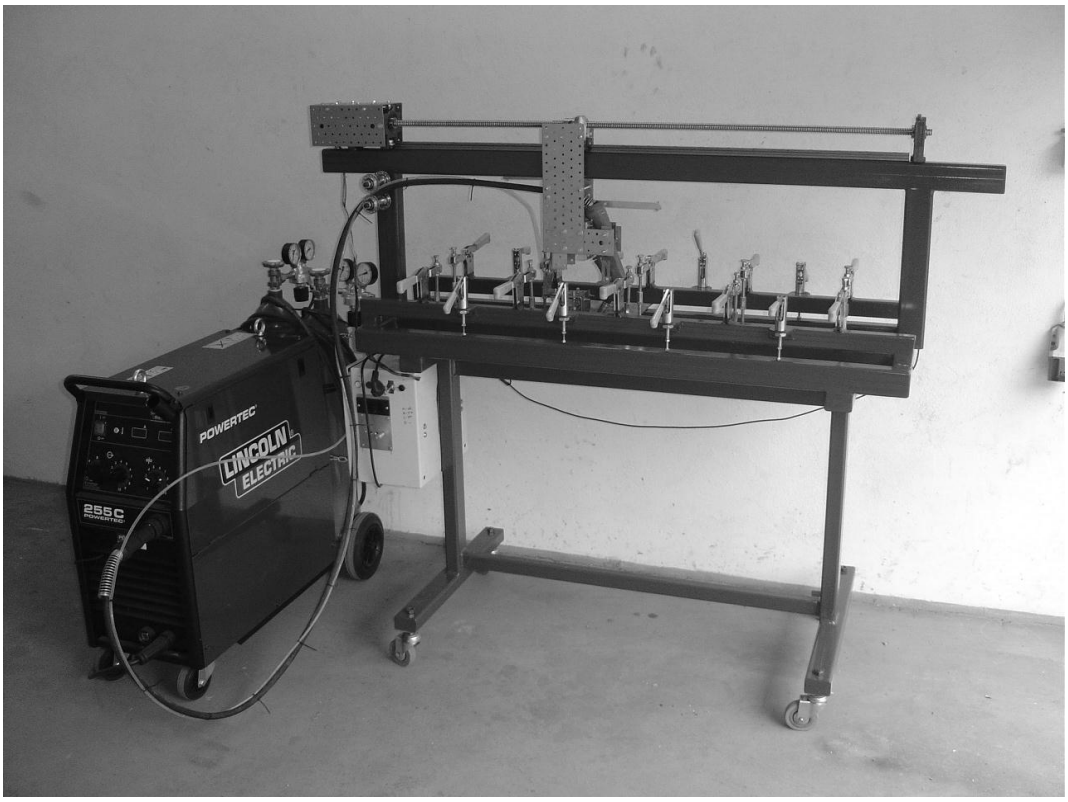

Fig. 4. Apparatus for welding with micro-jet injector
Rys. 4. Stanowisko do spawania wraz z chłodzeniem mikrojetowym

The welded elements are fixed by special clamps. It guarantees that all these elements are not deformated during the welding process.

Drive of the carriage is realized by the electrical engine where a precision nodular bolt is propelled by a clutch. Electric drive then is transferred to the electrical carriage by a precision nodular nut. Thanks to this solution, the electrical carriage moves in the linear plane and additionally there is a possibility to take precise control of a liner velocity of the carriage. Additionally, these solutions guarantee that a power transmission resistance is very little.

The part of the electrical carriage where the accessories are fixed is made from perforated plate because it enables to configure the apparatus for different needs, too.

There is possibility to change the distance between the welding clamp and the welded element and additionally the angle of inclination of the welding clamp may be changed, too. Moreover, the construction of this apparatus enables to change the distance between the welding clamp and the micro-jet accessory and the distance between the micro-jet accessory and the welded element.

The work parameters as well as control of welding process are controlled by control panel (fig. 5). The work parameters of the apparatus are presented in table 2.

Table 2

The work parameters of apparatus

Parameter	**Value**
Velocity of carriage	70 - 1200 mm/min
Return velocity of carriage	70 - 1200 mm/min
Length of linear advance of carriage	1 - 1000 mm

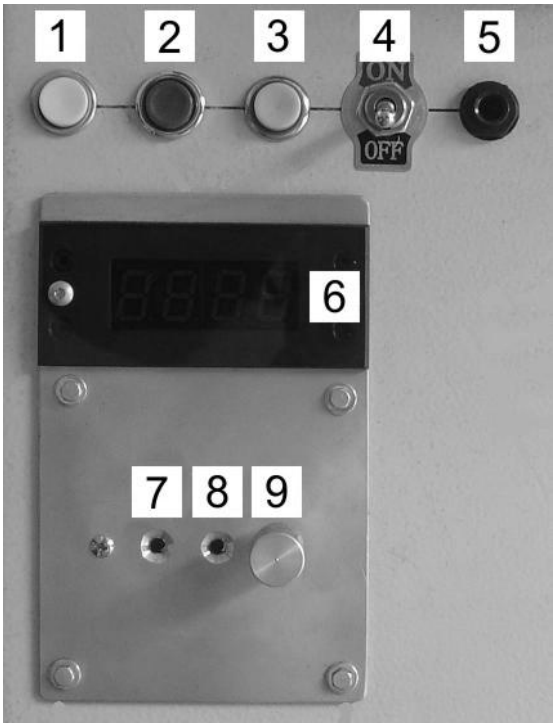

Fig. 5. Control panel of the welding apparatus: 1 – "start" push-button, 2 – "stop" push button, 3 – "carriage return" push button, 4 – "turn on" push button, 5 – plug-in of control conduit, 6 – display, 7, 8 – "menu" push buttons, 9 – "menu" handwheel

Rys. 5. Panel sterujący: 1 – włączenie, 2 – zatrzymanie, 3 – powrót, 4 – włączenie zasilania, 5 – podłącznie dodatkowego miernika, 6 – wyświetlacz, 7, 8 – przyciski regulacji parametrów, 9 – pokrętło regulacji parametrów

Cooling process of weld metal deposit is performed using argon that is delivered by gas bottle near the semi-automatic welder. The cooling gas pressure is controlled by pressure regulator on the gas bottle. In this process may be used another cooling medium, liquid as well as gas.

4. SUMMARY AND CONCLUSIONS

An innovative apparatus to welding process with micro-jet cooling of the weld made it possible to carry out technological tests, which have proved theoretical consideration about this problem. This project gives real opportunities for professional development in the field of welding with controlling the parameters of weld structure.

These tests have proved that the new micro-jet technology has the potential for growth. It may be great achievement of welding technology in order to increase weld metal strength. The new technology with micro-jet cooling may have many practical applications in many fields, like for example in machine industry or to repair damaged metal elements.

At the conclusion of that paper, it may be affirmed that:

a) Welding using the micro-jet accessory enables to control over the weld structure and the same over mechanical properties of welding joint.
b) In this project is proposed cooling min. 20 ºC/s in order to obtain the optimal structure.
c) The initial scientific researches were carried out using low-alloy steel where an effect of controlling the weld structure has been analyzed.
d) As a cooling medium were chosen argon and water.
e) MIG method was mainly chosen and tested for that project (micro-jet welding).

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