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CMT WELDING OF TITANIUM AND STAINLESS STEEL USING CuSi3 ELECTRODE

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Abstract

The article deals with the possibility of a tight permanent joint of X5CrNi 18–10 austenitic steel and UNS N50400 titanium. The nuclear and chemical industries are in particular interested in solving this problem. The joining by means of fusion welding has come up against unreliability due to the formation of brittle intermetallic compounds between titanium and iron. The article deals with joining of these two heterogeneous materials by an innovative CMT welding method. CuSi3 soldering electrode was chosen as the additional material. Protective atmosphere consisting of clean argon has been chosen due to the undesirable gas absorption by titanium at temperatures over 600 °C. The results will compare different welding parameters and their impact on the quality of the weld joint. The quality of the created welds will be verified on the basis of the tensile test and the results will be graphically visualized. The microhardness in the weld and its surroundings will be measured. The microhardness measurement results will be graphically displayed. The experimental results will be supplemented by macrostructure snapshots and metallographic analysis snapshots.

Keywords: soldering, weldment, argon, joint, tensile strength

INTRODUCTION

Welding is one of the most used types of metal joining. It is a permanent joint of two or more parts. CMT welding has been the biggest progress in the last years. This way allows welding of two heterogeneous materials under lower temperatures than other methods which was unthinkable until recently. Titanium has generally more demanding welding requirements; however it is used for its good properties as high strength at its relatively low density. Since it is used in prestigious fields, such as aviation, medicine or astronautics, big emphasis is laid already on production quality as well as its subsequent processing; the CMT automatic control method could be one the best choices for welding. CMT means Cold metal transfer, which could be translated into Czech as cold welding. It is a relatively new welding method, which is pioneered by Fronius. Formerly unthinkable welding of steel and aluminium that have very different thaw points (1540 °C for steel and 660 °C for aluminium) is now practised quite commonly. Nowadays, it is tested what other possibilities are hidden within this technology and what material will be possible to weld in quality manner in the future. This method has a big potential in the welding industry in the future (Kubíček, 2018; Motloch, 2011). Cold Metal Transfer welding is a modified MIG welding process based on short-circuiting transfer process (Talalaev *et al.*, 2012). From a technological point of view, the CMT method is soldering using an electric arc as a heat source for soldering the solder. For this reason, the concept of welding is used (Furukawa, 2006). The wire feed rate and the cycle arcing phase are controlled to realise sufficient energy to melt both the base material and a globule of filler wire (Pickin *et al.*, 2011). Stainless steels contain most frequently 18 up to 20 % Cr and 8 up to 11 % Ni with a content of carbon no more than 0.12 %. The steels with the carbon value over 0.12 % are not steels suitable for welding since chromium carbides causing intercrystalline corrosion are excluded. To ensure weldability, Nb or titanium are added and therefore they are very well weldable. Their resistance against corrosion is excellent and therefore they are suitable for the settings most susceptible to corrosion (Koukal, 2000; Ptáček, 2002).

For the welding of stainless steels, it is possible to use almost any kind of welding which will ensure a perfect protection of the weld. Particularly clean argon is used as protective atmosphere (Barták, 2002). Protective gasses are a very important part of the welding process. In particular, penetration wed, weld width, weld surface, the formation of notches are dependent upon them and they prevent the intrusion of air which would cause the weld oxidation. The CMT method is based on the MIG/MAG methods, and therefore these protective gases are very similar (Minařík, 2007). The CMT method uses inert gases such as Argon a Helium in welding. Their purity is decisive (Moravec, 2009). The main goal of the experiment was to create a permanent joint of X5CrNi 18–10 austenitic stainless steel and UNS N50400 titanium with a strength approximately 50 % of the Ti strength.

MATERIALS AND METHODS

The welding of stainless steel and titanium is difficult due to large differences in thermal, physical and chemical properties (Chen 2014). To fulfil the main aim, it was necessary to optimize the technological parameters in welding.

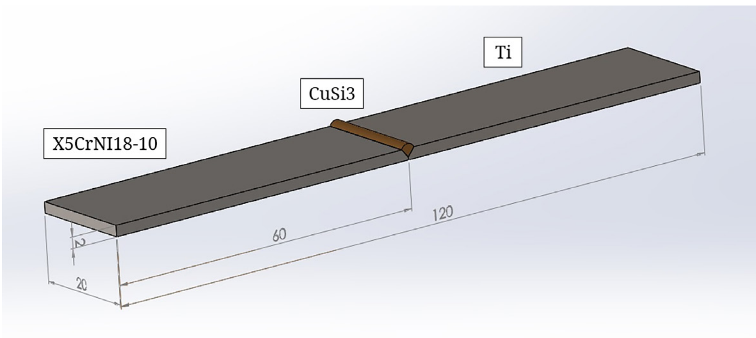
Material and equipment for welding

UNS N50400 titanium was supplied by Bibus metals s.r.o. X5CrNi18-10 austenitic steel was supplied by JM20 s r.o. Test samples characteristics see Tab. I.

2 millimetre sheets with the length of 300 mm (5pc) were welded, after the welding they were cut by ATA Brilliant 250X circular saw (under the influence of a cooling liquid in order to avoid the damage of the welds due to the heat caused)

I: *Test samples characteristics*

Base material 1	X5CrNi 18-10 stainless steel
Base material 2	UNS N50400 titanium
Additional material	CuSi3
Samples measurement (length × width × thickness)	120 × 20 × 2
Number of samples	75



1: *Welded samples measurements after the cutting* to 20 mm strips for samples for the tensile test. The total number of the cut samples was 75. The samples measurements are seen on Fig. 1.

The additional material (solder) for welding was a CuSi3 wire (S Cu 6560) – chemical composition 97 % Cu and 3 % Si.

The CMT (Cold Metal Transfer) welding method was used to melt up the CuSi3 soldering wire with a diameter of 1mm. CMT welding is a short-circuit arc-based process. In the case of conventional welding with short-circuit arch, the current is limited by winding or inductance in the current source. In the case of the current source for CMT, the increase of the current after short-circuit is limited by an electronic regulator. Digital regulation of the process detects a short-circuit and by pulling the wire supports release of the drop 90 x per second. The reverse movement of the wire supports the release of the drop during the short circuit. The short circuit is being checked and the current is maintained at a low value. The result is a spill-free transition of materials. From a technological point of view, it is soldering using an electrical arc as a heat source to melt the solder. For this reason I use the term welding in the article. The welding was carried out by Advanced 400 robot in Fronius, see Fig 2.

5 types of welding parameters were chosen in order to find out the most suitable welding conditions:

a) welding current: 150 A; welding voltage: 14,8 V; movement of the electrode: 9,5 m/min.; dynamics 0; burning height0.
b) welding current: 160 A; welding voltage: 16 V; movement of the electrode: 10,3 m/min.; dynamics 0; burning height0.
c) welding current: 140 A; welding voltage: 13,5 V; movement of the electrode: 8,8 m/min.; dynamics 0; burning height0.
d) welding current: 150 A; welding voltage: 14,7 V; movement of the electrode: 9,5 m/min.; dynamics 0,5; burning height-2.
e) welding current: 150 A; welding voltage: 14,7 V; movement of the electrode: 9,5 m/min.; dynamics – 0,5; burning height2.

In all welding parameters, the protective atmosphere consisted of 100 % argon due too the undesirable gas absorption by titanium at temperatures over 600 °C (Neumann 2014). Welding was done according to the standard ČSN EN ISO 6848.

Equipment for the tensile test

The samples were tested at a testing machine ZDM 5, which records digitally the values measured. The machine disposes of a maximum developed strength of 50 KN and a maximum length of the tested samples - 700 mm. The tensile strength test was performed according to the standard ČSN EN ISO 4136.

Microhardness measurement equipment

The used microhardness measurement equipment is the Struer Durascan G5 model. There was used the Micro Vickerse HV0.05 method where the indentor was pressed into the material under the weight of 50 g. The punctures would be always applied from the base material to the welding. Measurement of microtradition was done according to the standard ČSN EN ISO 6507-1.

IV. Metallographic analysis equipment

To prepare a scratch pattern, the material must be cut to the required size. The material should be cut off with ATA Brilliant 250X circular saw

2: *Fig. 2 CMT Advanced 4000 welding robot (Eder, 2010)* with cooling. The revolutions of the saw blade were 2500 revol./minute and the movement 0,6 mm/min. Pressing the sample into the PolyFast conductive resin was the next step. The pressing was performed on a Struers Cito Press 1 machine. It was very important to use the prescribed method of grinding and polishing for titanium. Both types of samples were grinded and polished in the same manner. The first step was a 5 minutes grinding on an abrasive paper with a roughness of 320 µm. The speed of the blade was 300 rpm with a thrust of 25 N. This grinding was followed up by polishing on the Alpha disc with the use of a wetting agent and 9 µm diamond suspension. The final step was polishing the samples on the omega disc, applying the OP-S suspension. Each step in polishing took 20 minutes and the revolutions of the disks were 150 rpm with a thrust of 20 N. In the next step, the porosity in the weld and root penetration were checked with the use of the Axio Vert A1 microscope. S8 APO stereomicroscope was used for optical analysis as well. The metallographic analysis was performed according to the following standards: ČSN 42 0460, ČSN 42 0466 and ČSN EN ISO 643.

RESULTS AND DISCUSSION

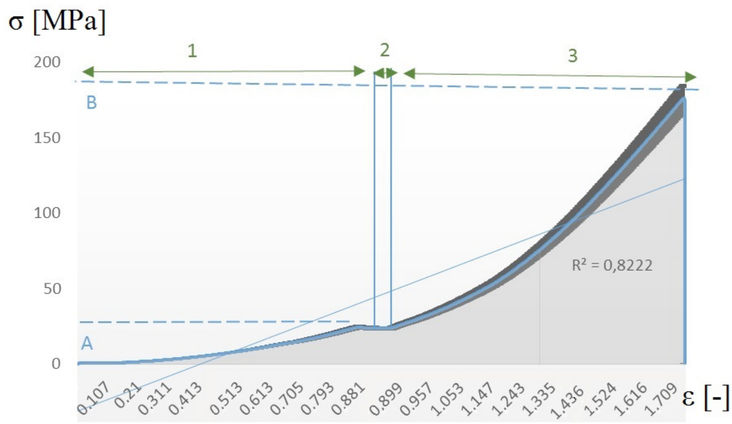
To evaluate the results of the experiment, it was necessary to measure and to evaluate the mechanical properties of the weldment, to document the macrostructure and microstructure of the joint. Out of 5 selected welding parameters (designated as a, b, c, d, e), we have managed to create a heterogeneous permanent joint of stainless steel and titanium by means of CuSi3 soldering electrode in 3 cases (designated a, d, e). The remaining two parameters (designated as b, c) were unsuitable due to the occurrence of cracks.

The tensile strength test was chosen in order to evaluate the mechanical properties of the successfully performed welds. Good results in the tensile test were achieved only in using the welding parameters designated as a). The d) and e) parameters did not show a sufficient tensile strength due to the formation of fragile compounds between FeTi and Fe2Ti (Pardal 2016). The results of the tensile tests using the welding parameters designated as a) were very similar. The best achieved tensile test results using CuSi3 electrode are shown on the selected sample and visualised at Fig. 3.

A representative sample was selected from the samples with the best properties. The chart at point B shows the maximum stress needed to break the weldment which amounted to 176. The relative elongation of the ε of the soldered joint at the break was 1.70, which is 170 % of the original length of the soldered joint. Before the tensile test, the CuSi3 soldered joint had a length of 1 mm, after the break it has extended to a length of 2.70 mm. The base materials did not elongate after the tensile test since their yield strength was not exceeded.

Point A shows stress on yield strength of the weldment which amounts to 24 MPa.

In area 1, only flexible deformation occurs, area 2 is yield stress and in area 3, plastic deformation occurs. In Pardal *et al.* 2016, the resulting weld strength values were in the range of approximately 50–200 MPa. In Chen *et al.* 2014 were the highest values of weld strength of 150 MPa. The macrophotography in Fig. 4 shows a brittle fracture of the weldment. From the CuSi3 solder adhered to stainless steel and



3: *Tensile test results*
Legend: A (stress on yield strength) = 24 MPa; B (stress on strength)) = 176 MPa
1 – flexible deformation area; 2 – yield strength; 3 – plastic deformation area

titanium it is obvious that the joining was provided by the diffusion process. The heat-affected area is also visible on the figure.

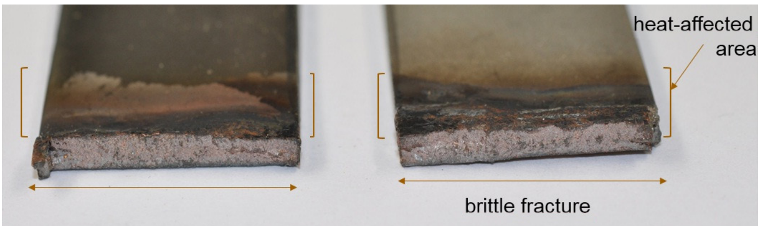
The cross-section macrostructure in Fig. 5 obviously shows that there was a partial melting both on the part of the stainless steel and on the part of titanium due to influence of the heat input of the CuSi3 solder.

Fig. 6 illustrates the course of microhardness starting from stainless steel – area 1 to solder – area 2 up to titanium, area 4. As the alloy of titanium and copper was formed in area 3, there was a considerable increase of hardness due to the influence of hard intermediary metal phases (Neumann 2014).

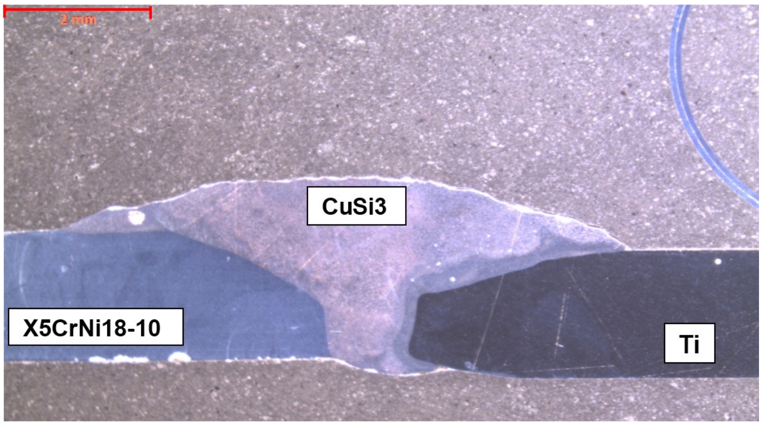
It is important that there was no fracture in this alloy during the tensile test. A microstructure analysis was conducted at the place of measured results of hardness that showed a high.

Microstructure analysis was conducted at the place where hardness results indicating a large increase in hardness were measured.

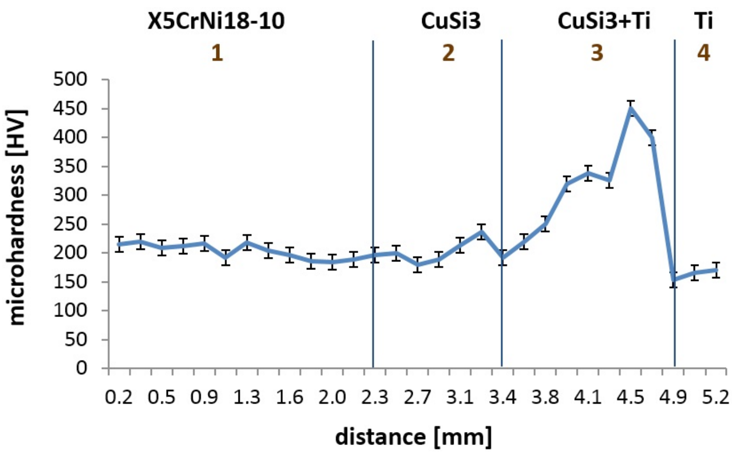
The metallographic analysis snapshot in Fig. 7 performed by S8 APO stereomicroscope was the result of the measurement at the place of higher weld hardness.



4: *Brittle fracture of the weldment*

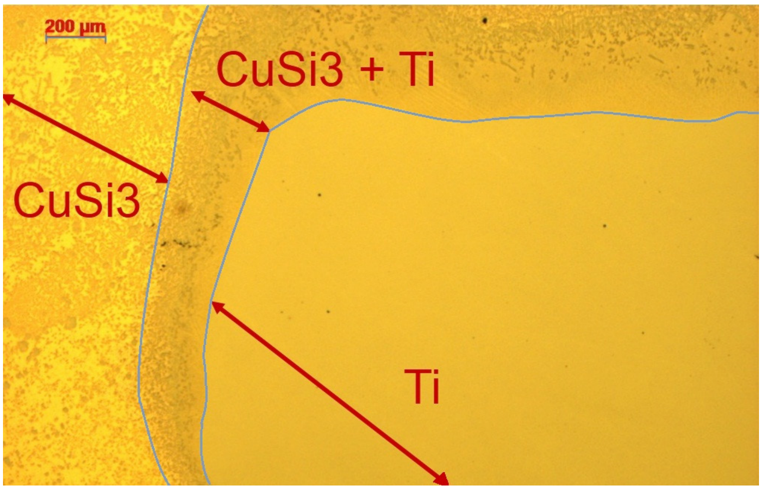


5: *Cross-section macrostructure*



6: *The course of microhardness*

Legend: 1 – stainless steel; 2 – CuSi3 solder; 3 – CuSi3 alloy + Ti; 4 - titanim



7: *Welding zone microstructure*

In certain areas, the welding temperature can rise up to over 1600 °C. In CMT welding, the base material can be melted by the CuSi3 solder which is surprising information. The structure of the welding zone in Fig. 7 shows that titan was partly melted and a hard alloy of titanium and copper was formed. Clear titanium can be seen on the microstructure. The alloy of titanium and copper where there was fusion welding on the surface layer. And a solder consisting of copper and silicates.

CONCLUSION

CMT welding is suitable for joining of heterogeneous materials (Poláková, *et al.* 2017).

In Pardal *et al.* 2016, the resulting weld strength values were in the range of approximately 50–200 MPa. Pardal heat input evaluates the dominant parameter during the study.

At Fronius, the most suitable parameter setting was gradually optimized. The welding was done in 5 different parameters. 15 samples were created in each setting. An ideal welding parameters setting with the best results was chosen on the basis of the tensile test.

The optimal current and voltage characteristics in the CMT welding method was 150 A and 15 V. The movement speed of the CuSi3 soldering electrode 8.5 m / minute. The maximum tensile strength achieved in the welding using the CMT method was 176 MPa. The main goal of the experiment to achieve a weld strength of about 50 % of Ti strength has been successfully achieved. Using an electric arc as a heat source is very demanding in terms of energy dosing. In the experiment, there was a classical soldering with a surface diffusion layer in a part of the joint and stainless steel whereas in other places, there was a melting joint of the solder and stainless steel and melting joint of solder and titanium. The great increase of hardness in the alloy of Cu + Ti did not affect the strength of the joint since the joint was impaired during the tensile test in the solder material.

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