

DEGRADATION PROCESSES OF AL-ZN WELDED JOINTS

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Abstract

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Welding of metal materials belongs to non-demountable joints. Current trend especially in an automotive industry is to join materials with a different melting temperature. Most of all, there are dural profiles with ferrite or austenite steel. The reason for this is the effort to lower the weight of the whole construction and at the same time preserve sufficient mechanical characteristics. However, there is a big risk of different electrical potentials of both of these metals in this type of non-demountable joints.

The experimental part of this paper brings evaluation of mechanical-corrosion processes of overlapped joints produced by the CMT (cold metal transfer) method. The base material for weld bead is dural sheet AlMg3 and dural sheet with a surface treatment aluzinc DX51D+AZ 150. Material AlSi5 in the form of a wire was used as an additional material for a welding bath. Method CMT was used in order to create a weld bead.

Initial analysis of weld bead was done visually using a binocular microscope. Further, a metallographic analysis of weld bead and base material was processed. The aim was to identify the heat affected area around the welded joint. Microhardness of intermetallic aluminium phases was measured, after the identification of intermetallic phases a chemical analysis EDS was processed.

Prepared samples underwent corrosion degradation in a salt spray environment in compliance with the norm ČSN EN ISO 9227. Visual and metallographic evaluation of the individual samples was processed after every week of exposition to the salt spray environment. The goal of this experiment was to record the initial impulse of galvanic corrosion which consists in corrosion degradation in the area of welded joint.

Keywords: corrosion, welded point, CMT, zinc, dural

INTRODUCTION

Joining metal materials by welding is a basic technological process in engineering production. There are many welding technologies: arc, fusion, CMT, explosive, friction etc. Current trend in engineering production is laser welding, which is a method minimizing immixture of welded metals (Daňko *et al.*, 2011; Paulíček *et al.*, 2013). Each of these technologies influences crucially tenacity and inner structure of the welded joint (Taban *et al.*, 2010).

In the process of joining heterogeneous materials (dural alloys + anticorrosion steel, dural + zinc-coated steel) with a different electrolyte potential there may occur efficient conditions for the origin of galvanic corrosion. Less noble metal (aluminium

alloy) corrodes much faster and there appears a total degradation of welded joint. (Ščerbejová, 1993; Trethewey, 1995; Davis, 2000). There is also a problem of intermetallic phases originating in the transition of welded joint and base material. These intermetallic phases, which are compound of base elements Al, Zn and Fe, reach up to a number of μm and are extremely fragile (Marder, 2000).

At the weld bath surface, there also grow up Al_2O_3 in the process of dural welding. This compound has to be removed from the weld bath surface by well-defined welding parameters. In case of insufficient purity of weld metal, there is a big risk of intrusions in the weld bead. (Országh, 1998; Mandal, 2002). Weld metal as well as base

material are subject to corrosion degradation and it is necessary to undertake a proper anticorrosion protection. In joining heterogeneous materials it is not possible to use classical methods, such as zinc dipping. Organic coatings are used as anticorrosion protection of these weldments. (Chovancová *et al.*, 2010). However, there is a disadvantage of different anchoring profile of both of the materials.

MATERIAL AND METHODS

In general, it is impossible to weld using the arc method such metals, whose physical properties, such as melting temperature, coefficient of expansion, and electrochemical potential, are entirely different. From this reason it is not possible to use the classical method (MIG/MAG) for joining dural and zinc coated steel. These methods are appropriate both for welding and for deposition of hard metal materials. The MIG/MAG methods are being used mostly for renovations of abrasive-stressed parts. (Kotus *et al.*, 2010; Špendle *et al.*, 2011)

However, in various industries, there is a need of using the combination of these two technical materials (Dillinger, 2007). Using the CMT (cold metal transfer) technology, it is possible to use electric arc in order to achieve a quality welded joint.

Characteristics of welded materials:

- Zinc coated steel sheet: It is a classical construction material used in a usual technical engineering practice. The base is formed by a ferrite-pearlite steel class 11, whose surface treatment consists of a combination of passivating elements according to the chemical composition of a melting bath. They are zinc and aluminium intermetallic compounds. The thickness of passivating coating is up to 30 μm and is guaranteed by zinc dipping method and removing the excessive material by nitrogen.
- Dural sheet (smooth): is a readily available technical material. Chemical composition of the base material is formed by the following elements: Mg (3%), Si (0.5%), Cu (0.1%), Mn (0.4%) and aluminium (rest). Commercially, the sheet is labelled as AlMg3.
- Additive material: Additive material used for this experiment was a solid wire (AlSi5). This material

is appropriate for welding of dural alloys, such as AlMgSi and AlSi with the content of Si up to 7%. Chemical composition of the wire itself is 95% Al and 5% Si.

Basic welding parameters: Weld beads were produced on a welding robot using the cold metal transfer method. Protective atmosphere of welding bath consists of 100% of Ar. The speed of welding jet was 10 to 14 $\text{m}\cdot\text{s}^{-1}$. Welding current for materials up to 2 mm was set at 59 A. Flow of the protective gas depending on the speed of welding jet was 10 to 16 $\text{l}\cdot\text{min}^{-1}$. Electric voltage of the welding aggregate is 11.5 V. (Modenesi *et al.*, 2000, Yang *et al.*, 2013)

Using the CMT technology, there were prepared several samples for corrosion mechanical tests. The following tests were processed:

- visual evaluation of weld bead (cracks, flushes at the welding bath edges),
- metallographic analysis with the evaluation of microhardness of the base materials,
- chemical composition of intermetallic phases in the weld area,
- corrosion tests in the salt spray environment according to the norm ČSN EN ISO 9227,
- analysis of change of mechanical characteristics (tensile stress resistance).

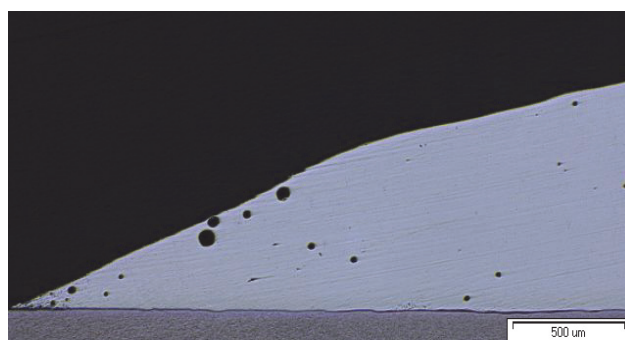
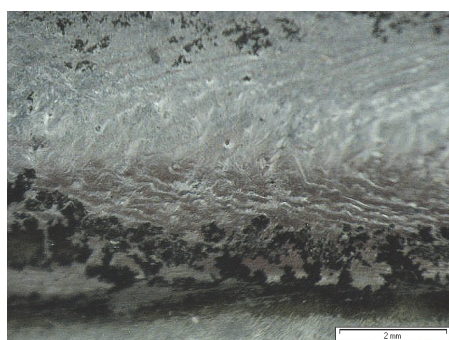
RESULTS AND DISCUSSION

Evaluation of Weld Bead

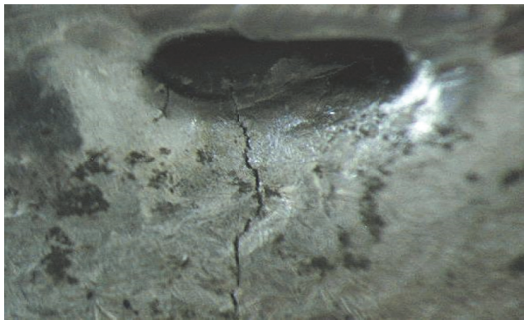
In the welded joint, there origin pores and cracks in dural welding. CMT method allows eliminating the described negative aspects.

In welding, the dural profile is melted, on the other hand, zinc coated steel has only a solder joint. The advantage of this method is a lower temperature comparing to classic welding (Adamiec, 2005). However, as it is apparent from Fig. 1, pores can be observed also in tested samples.

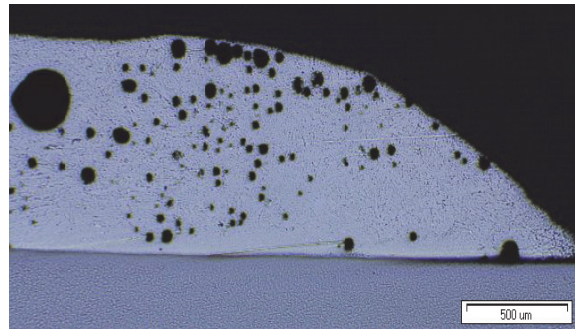
The main benefits of this method are first of all, that plastic deformations of welded joint are minimised, further, spray of weld bath is insignificant, moreover, firmness of the joint is high, and the need of further machining operations of weld bead is also lowered.



1: Welded joint, method CMT



2: Welded joint, method "synchropulse"



Selection of welding parameters as well as selection of a welding robot has a crucial effect on the quality of weld bead, see Fig. 2. When welding dural profile to zinc coated steel, there was processed also a test of settings of oscillating welding jet "synchropulse". This method requires increase of welding current to 75 A. However, this method causes pores at the edges of welding bath, see Fig. 2. These welding parameters are completely inappropriate for the given materials.

Metallographic Analysis

In order to prepare metallographic specimen methyl acrylate moulding resin was used. Metallographic samples were evaluated on a metallographic microscope Neophot 2 using the software analySIS for deduction of length parameters.

During the welding process, the anticorrosion protective coating aluzinc is being smelted. As it is apparent in Fig. 3, the steel ferrite base has a combination of Al-Zn elements on its surface. There were identified intermetallic phases of 10 μm in size. Rough pins of aluminium alloys intervene

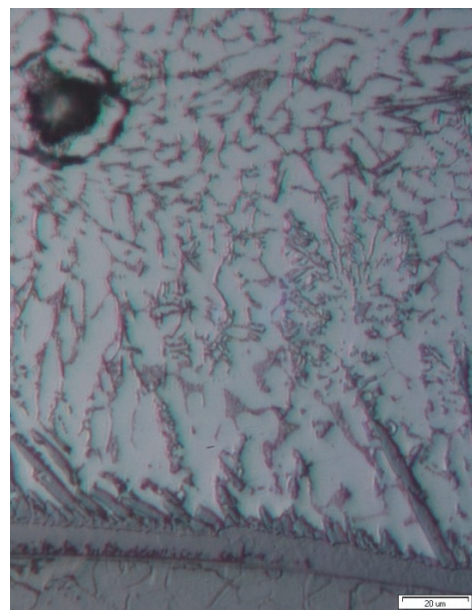
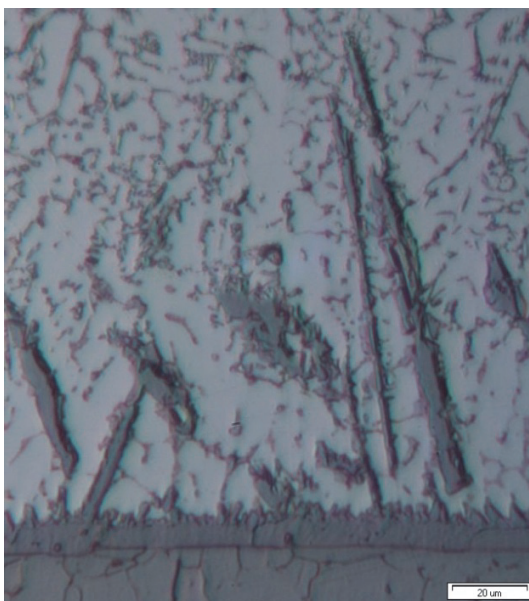
in welded metal itself. Potential corrosion resistance of welded joint may be lowered due to a big electrolyte tension difference: Fe (-0.44) and Al (-1.33).

Transition area between weld metal and base material is affected by different dilatation of both materials. This area is subject to formation of pores, hollows and cracks. As it is apparent from Fig. 4, the inhomogeneities may reach to lengths bigger than 20 μm.

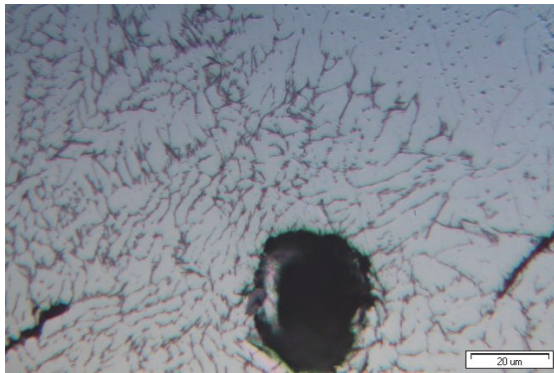
Measuring Microhardness of Structural Phases (ČSN EN ISO 4516)

Microhardness is one of the basic indicators of structural phases of the material. Chemical composition of weld material influences intermetallic phases in the inner structure.

In order to measure Microhardness of structural phases of weld metal, heat affected area and base material, Hanneman's microhardness tester in the combination with a metallographic microscope Neophot 21 was used. Measurement system was derived from Vickers: a diamond cone with an apex angle of 136 ° is being pressed to



3: Soldered joint



4: Transitional area of weld metal

the material. According to the lengths of diagonals, microhardness HV is being read.

Microhardness was measured in weld metal, heat-affected area and base material. Measurement was processed on 3 samples of each welding technology, 5 measurements per each area. Average values of the individual readings are recorded in Tab. II. In order to analyse mechanical characteristics, there was measured also microhardness of transitional area between base steel material and weld metal (that is Al-Zn phases). As it is a thin coating of ca. 5 μm it is impossible to eliminate the measuring error of testing cone, see Fig. 4. Measured values are recorded in Tab. II.

From the values recorded in Tab. I, it can be stated that both heat-affected area and welded joint have very similar values of microhardness of the individual structural phases. However, there is a big difference between the values

of microhardness of welded joint and base dural material. This aspect may have a negative effect of mechanical load of welded joint (Bruckner, 2005).

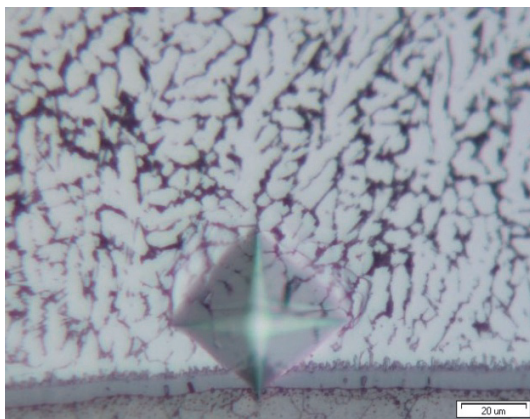
Analysis of Element Composition of Metal Coating

Additive welding material forms a main component of welded metal. Combining more metals, higher firmness of welded joint can be achieved. Experimental tests are also being processed with Cu elements. (Shang *et al.*, 2012)

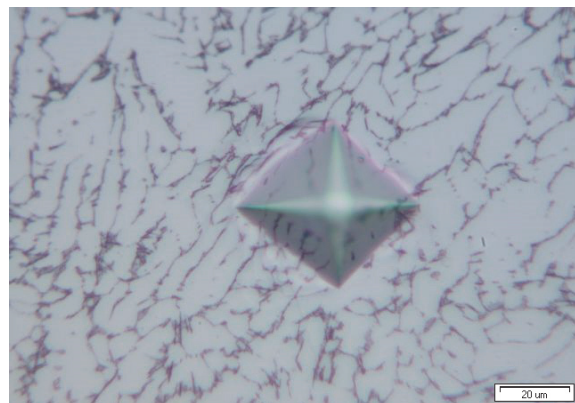
A scanning electron microscope VEGA II XMU (produced by the company Tescan) was used for the microanalysis of the elemental composition, in connection with energy dispersive microanalyser QUANTAX 800. The measurement of the elemental composition of a sample was performed on three different pads using a 100-time multiplication. The accelerating voltage equaled 15 kV. The readings are equal to mass concentration of 100%. The results of measurements of the chemical composition of the individual metal layers are presented in Tab. II and they show the average value obtained out of three measurements.

Anticorrosion coating of the base steel material is formed by a composition of aluminium and zinc, whose chemical composition slightly differs from the declaration of the producer.

The quantitative analysis used the intensity of the line drawn by the individual chemical elements; see Fig. 6, which serve as an input for the evaluation software.



5: Impress in base weld metal

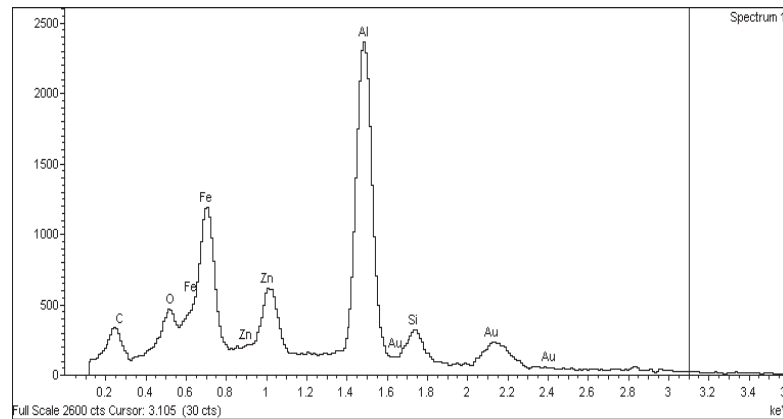


I: Microhardness values

Measured area	Measurement of microhardness in the individual areas HV _{0.1}					Average
	No. 1	No. 2	No. 3	No. 4	No. 5	
Welded joint	86	91	85	85	98	89.0
Heat-affected area	65	63	68	68	61	65.0
Base material – dural	38	36	38	36	36	36.8
Base material – steel	224	227	227	219	224	224.2

II: Chemical composition of weld bead

Area	Spectrum			
	Al [% _{mp}]	Si [% _{mp}]	Fe [% _{mp}]	Zn [% _{mp}]
Welded metal	70.10	0.80	3.25	25.86
Anticorrosion coating of the base material	50.55	0.35	8.35	40.75
Transition area in welded joint	43.86	6.69	39.62	9.83



6: EDS spectrum of the weld metal, for results of the chemical composition see Tab. II

Assessment of Corrosion Resistance of Protective Coatings

Corrosion resistance of the individual protective systems was tested according to the norm ČSN ISO 9227 – *Salt spray test (NSS method)*. Salt spray chamber Liebisch type S400M-TR was used for this experiment.

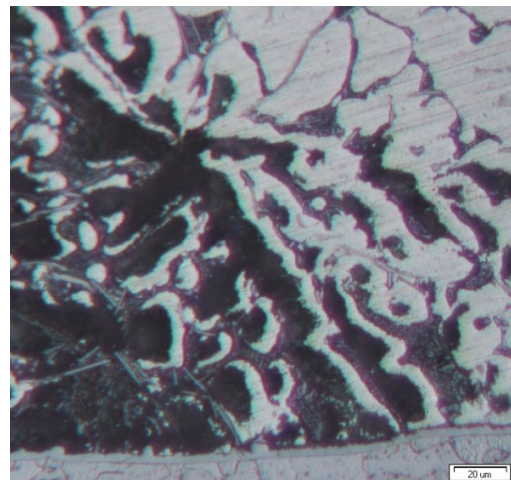
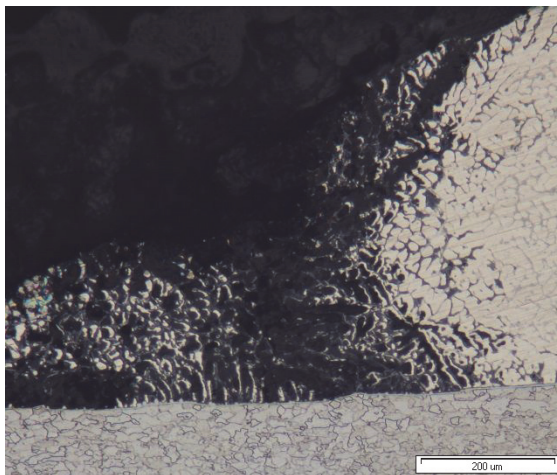
Testing parameters:

- temperature in the salt-spray chamber $35 \pm 2^\circ\text{C}$,
- concentration of the sodium chloride in a spraying medium $50 \pm 5\text{ g/l}$,
- pH value of the salt solution 6.5–7.2,
- the time interval was set for 10, 20, and 30 days. Based on an every-day visual evaluation

and depending on the speed of corrosion degradation, the individual intervals may differ.

There were prepared 20 testing samples using the welding CMT method. Samples were placed to a special hanger and were subject of aggressive corrosion environment. Corrosion attack was evaluated visually on a contact surface.

As after a 1-week exposition to the salt-spray environment, there was not visually noted an increased degradation of welded joint, there were prepared metallographic samples. As it is apparent from Fig. 7, the initial degradation phase occurs at close quarters of the base steel material. Firstly, the particles in the welded joint are attacked by corrosion. Higher corrosion resistance is being observed in the areas with higher content of Si.



7: Corrosion degradation of welded joint after 10 days

III: Resistance to tensile strain before the corrosion test

Measured values	Measurement of resistance to tensile strain before the corrosion test					
	No. 1	No. 2	No. 3	No. 4	No. 5	Average
Fm [N]	2540	2501	2522	2542	2513	2523.6
Rm [MPa]	84.60	83.36	84.06	84.73	83.76	84.102



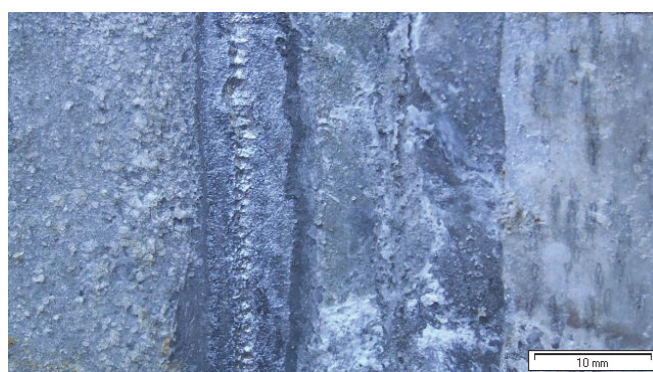
8: Failure of material next to the weld bead

IV: Resistance to tensile strain before the corrosion test after a 10-day salt-spray exposition

Measured values	Measurement of resistance to tensile strain					
	No. 1	No. 2	No. 3	No. 4	No. 5	Average
Fm [N]	2555	2534	2540	2536	2529	2538.8
Rm [MPa]	85.16	84.46	84.66	84.53	84.30	84.622

V: Resistance to tensile strain before the corrosion test after a 20-day salt-spray exposition

Measured values	Measurement of resistance to tensile strain					
	No. 1	No. 2	No. 3	No. 4	No. 5	Average
Fm [N]	1552	1493	1509	1521	1498	1514.6
Rm [MPa]	51.73	49.76	50.30	50.70	49.93	50.484



9: Sample after a 20-day exposition to the salt-spray environment

Change of mechanical characteristics of welded joint is directly proportional to corrosion attack. When joining metals with a different electrical potential, there occurs galvanic corrosion, which widens itself at the borders of particles of the individual materials. In order to prove the above mentioned statement, there was processed a tensile test. Gradual increasing deformation of test

specimen shows rapid lowering of tenacity of tested welds, see Tabs. III–VI.

In the initial phase the material was defected next to the weld bead, see Fig. 8.

Owing to galvanic corrosion, there also occurs degradation of samples under the weld bead, see Fig. 9.

VI: Resistance to tensile strain before the corrosion test after a 30-day salt-spray exposition

Measured values	Measurement of resistance to tensile strain					
	No. 1	No. 2	No. 3	No. 4	No. 5	Average
F_m [N]	1152	1132	1179	1162	1153	1155.6
R_m [MPa]	38.4	37.73	39.30	38.73	38.43	38.518

CONCLUSION

Welding of heterogeneous materials belongs to dynamically developing subjects. The reason is to produce a skeleton or a construction with a lower possible weight with a maximal possible sturdiness. However, the idea of welding heterogeneous materials has a big risk of galvanic corrosion which occurs in the transitional area of joint of both materials. As the corrosion degradation process takes place within the welded joint, there is a risk of a sudden total destruction of the produced part without previous visible signs of corrosion attack.

The paper is focused on an overall monitoring of corrosion processes of welded joints produced by the CMT method. Base material in this experiment was zinc coated steel DX51D+AZ150 and a dural strap (AlMg3). Weld beads were than subjected to an aggressive salt-spray environment.

Before corrosion tests the quality analysis of individual test specimen was processed. Porosity and level of smelting with the base material were assessed. Microhardness of base materials and weld metal was measured. Chemical composition of transitional areas of weld bead was determined using the EDS method. In order to identify decrease of tenacity of welded joint a tension tests were also processed during the corrosion tests.

Based on metallographic scratch patterns, there was proved a considerable porosity of the weld bead. The origin of the pores is caused by large absorption of gases from the environment. There occur absorption, diffusion and melting of gases at the surface as well as in the weld bead inside. Hydrogen which is well-soluble in dural has the biggest influence on the origin of pores. Air humidity may also have a partial influence on the origin of cracks and pores in the welding process.

Weld beads were produced by the CMT and "synchropulse" methods. The difference between the two methods is in the setting of welding parameters and a different working of welding jet. Samples welded by "synchropulse" method were rejected from further tests as the tensile test has showed a total destruction of weld bead.

The exposition of samples to the salt-spray environment was set to the time intervals of 10, 20 and 30 days. During the exposition, there were not noticed any visible changes, which was the reason to process metallographic analysis of length of undercorroded weld metal. According to the tensile tests, the tenacity of welded joints was lowered by 50%.

SUMMARY

This paper is focused on preparation and evaluation of CMT weld joints. The advantage of this method consists mostly in welding thin metal sheets up to 2 mm thick, anticorrosion steels and in joining heterogeneous materials, such as dural and zinc-coated metal sheets, where zinc coating serves as a welding flux and wets the steel. Thickness of the zinc coating should be between 10 to 30 µm, which guarantees maximal tenacity of welded joint.

Based on the metallographic analysis it can be stated that hydrogen has a good solubility in welded metal, which influences the amount and size of pores in the weld bead. Mostly, the pores have a circular cross section with the diameter of up to ca. 15 µm. According to the metallographic analyses, there were also proved intermetallic phases of dural alloys between the base steel sheet and weld bead. The thickness of the transitional layer between the base material and weld metal was from 2 to 5 µm.

In order to analyse mechanical characteristics, microhardness of the individual structural phases was measured. In welding of dural alloys, the hardness in the weld joint area is lowered. Tests have shown values around 65 HV_{0.1}. Chemical analysis proved a high diffusion of Fe to a transitional layer of weld joint: there was measured ca. 40%_{mp} ferrum in this area.

Tests according to the norm ČSN EN ISO 9227 have however proved enormous corrosion attack in the form of galvanic corrosion. There is formed a corrosion micro couple: metal with a more negative potential becomes an anode and corrosion (oxidation) processes run here. From this reason, red corrosion was not observed as steel sheet was protected against corrosion. Corrosion degradation changes proceeded in the semilayer of weld bead.

From the point of view of lowering weight of constructions and skeletons is combining joining heterogeneous materials a significant trend in engineering. The wide usage CMT method is designed mostly for the automotive industry, especially for the production of coachwork. However, it is necessary to take into consideration also the risks of joining two metals with a different electrolyte current.

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