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# PROTECTION OF WELDED JOINTS AGAINST CORROSION DEGRADATION

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## Abstract

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Welded joints form an integral part of steel constructions. Welded joints are undetachable joints, which are however subjects of corrosion processes. The internal energy increases during the fusion welding especially in the heat affected places around the welded joint, which become initiating spot of corrosion degradation.
The aim of the experiment is to put a welded joint produced by the MAG method to a test of corrosion degradation under the conditions of the norm ČSN ISO 9227 (salt-spray test). Organic and inorganic anticorrosion protections were applied on welded beads. First of all, there were prepared welded beads using the method MAG; secondly, metallographical analyses of welded metal, heat affected places and base material were processed. Further, microhardness as well as analysis of chemical composition using the EDS microscope were analysed.
Based on a current trend in anticorrosion protections, there were chosen three types of protective coatings. First protective system was a double-layer synthetic system, where the base layer is formed by paint Pragroprimer S2000 and the upper layer by finishing paint Industrol S 2013. Second protective system is a duplex system formed by a combination of a base zinc coating with Zinorex paint. The last protective system was formed by zinc dipping only. Corrosion resistance of the individual tested samples was evaluated based on degradation of protective coating. The corrosion origin as well as the corrosion process were observed, the main criteria was the observation of welded bead.

weld, corrosion, anticorrosion protection, welding, welded bead

Welding belongs to basic technological processes of production of technical constructions. It is a process of joining of individual separate parts into an undetachable unit. The principle of welding consists in creation of a metallurgical joint; that is a joint based on operation of interatomic building powers which cause cohesion and durability of metal (Němec *et al.*, 2006). There is a wide variety of technologies to process a welded joint.

One of the widely used welding technologies is "Metal Active Gas" method, abbreviated as MAG method. It is a semiautomatic welding of metals in protective atmosphere of active gas, such as pure $CO_2$, and either 82 % Ar + 18 % $CO_2$ or 97 % Ar + 3 % $O_2$. Pure carbon dioxide not only ensures a good penetration, but also fuels forming of oxides and carbides which have a negative effect on mechanical characteristics of welded joints (Minařík, 2003; Koukal, 2005). Further disadvantage of pure carbon dioxide can be seen in a considerably high voltage on electrode which results in a high spray of welded metal. This active gas is used for welding and burning-in of unalloyed and low-alloyed construction steels, on the other hand it is not appropriate for highly alloyed steels, especially those of class 17.

No matter what kind of active gas is used for welding, base material is being affected by internal stress which results not only in a change of mechanical characteristics of the base material but affects, but also the speed of corrosion spreading in the neighbourhood of the welded joint (Hřivňák, 2009).

Choosing the most fitting material and choosing the best construction solution of the machine part is one of the prior elements of anticorrosion protection of not only welded constructions. Further criterion of anticorrosion protection is the appropriate anticorrosion coating applied on the base material. There are distinguished two kinds of anticorrosion protections: organic and inorganic (Ambrož, 1990; Ščerbejová, 1993; Dillinger, 2007). The protective principle of organic coatings is to eliminate air humidity from the access to the base material. The quality of such a barrier is affected by many external factors. Inorganic coatings consist in nobleness of passivating metals comparing to the base material.

## MATERIAL AND METHODS

In order to prepare welded beads, base material S235JR (11 373) was used; it is a silicon iron with a good welding performance no matter which welding method is used.

### Preparation of the Base Material

First of all, there were cut samples sized 50 × 25 × 3 mm from the base material. Further, these steel sheets were mechanically cleaned and disinfected. In order to remove the grease, the preparation "Perchlor" was used. Grease removal is an important operation as the degradation of fatty acids during the welding process results in a considerable worsening of the quality of the welded joint.

### Welding Using MAG Method

MAG method belongs to the most common ways of welding of ferritic steels. As this method guarantees a high quality of welded joints and there is a low risk of degradation of welded metal in the form of slag-forming element, this method is being used instead of arc welding. Nevertheless, this method cannot be recommended for welding of austenite steels as can be the TIG method (Országh, 1998; Hřivňák, 2009).

### Additive Material

There was chosen a classical steel wire whose surface was coated with copper (Cu), for the experiment wire MAG Weld G3Si1 was used. This additive material was introduced to the welding bath by the means of welding element. Chemical composition of the wire was analysed on an electrone microscope TESCAN using the EDS method. Chemical composition of the additive material (wire Weld G3Si1) and the base material (11 373) is written in Tab. I.

Weld G3Si1 is an appropriate material for welding both corner and butt joint in all welding positions. Welding can be processed in both mixed atmosphere of Ar/$CO_2$ and in pure carbon dioxide.

### Anticorrosion Protection: Hot-dipped Zinc

Zinc hot-dipping belongs to the most common anticorrosion protections against undesirable effects of the environment. The technology consists of application of melted metal (zinc) on steel elements. While dipping the machine part in the melted zinc bath, there origins a diffusion alloy coating, which on one hand positively influences the adhesion; on the other, is very fragile (Chovancová *et al.*, 2010).

The technological process of zinc-dipping was processed in laboratory conditions with defined values of chemical composition of zinc bath and time restriction on dipping.

### Anticorrosion Protection by Syntetic Coating

Anticorrosion protection by synthetic coating was made by two layers: base paint Pragroprimer S2000 and hiding paint Industrol S 2013. The individual systems were sprayed in two layers to the base material, the break between spraying the other coating was minimally 4 hours, temperature the environment was 22 °C.

### Duplex System of Anticorrosion Protection

Duplex system is a kind of anticorrosion protection which was designed up to 60 years and is formed by a combination of metal base and an appropriate upper paint (Svoboda, 1985; Trethewey, 1995; Votava *et al.*, 2011). The duplex system used in this experiment was formed by a zinc-dipped coating and a top one-layer of acrylate paint Zinorex.

## RESULTS AND DISCUSSION

### Metallographic Analysis of Welded Joints MAG

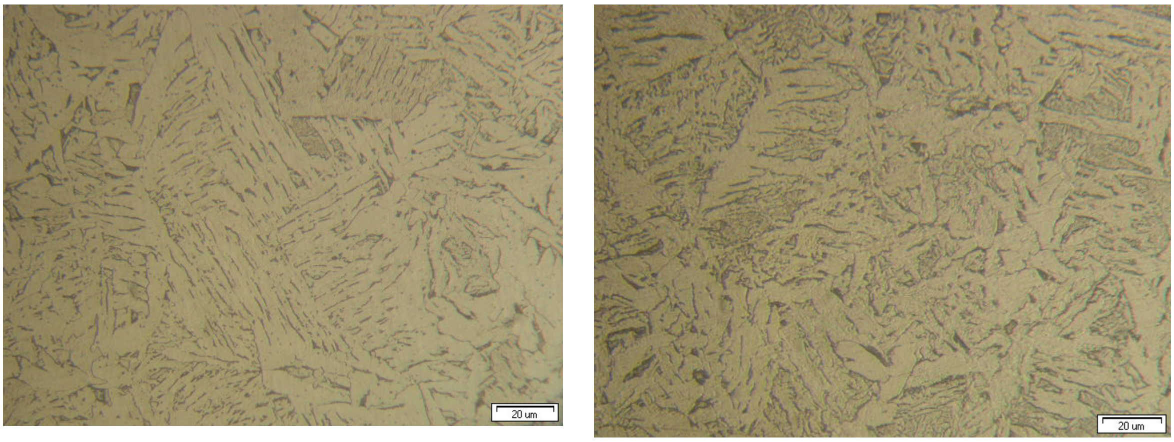
Nowadays, the MAG method is the most widely used welding method. It is also used in repairs as it is possible to weld steel sheets of different profiles and thicknesses up to 1 mm.

Samples were welded by semiautomatic welder KIT 169, the feed speed was 2.8 m per minute.

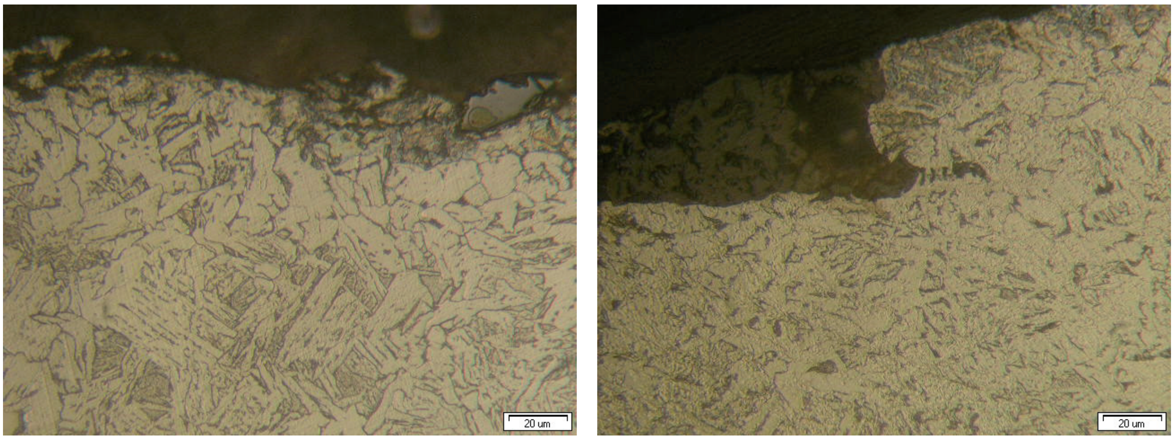
The structure of the welded metal depicted in Fig. 1 is formed by a combination of ferrite and Widmanstatten's structure. As ferrite grains are dominant, it can be stated that the welded joint performs a good ductility. Pearlite is partly excluded to grain outskirts, mostly in lamellar form.

I: *Chemical composition of the used materials*

| Kinds of used materials | Chemical composition [$\%_{mp}$] | | | | | |
|---|---|---|---|---|---|---|
| | C max | Mn max | Si max | P max | S max | Cu |
| **Weld G3Si1** | 0.090 | 1.500 | 0.900 | - | - | 0.200 |
| **Base material 11 373** | 0.170 | - | - | 0.045 | 0.045 | - |




1: *Welded metal, MAG method (left), heat affected area (right)*




2: *Scap after welding using MAG method*

A very similar structure can be found also in a heat affected area. As it is apparent from Fig. 1, ferrite overweighs. The carbon content enables the origin of transient phases and there can appear a bainitic transition, which can however be identified only by an electron microscope.

## Foreign Matters and Penetrations at the Weld Bead Margins

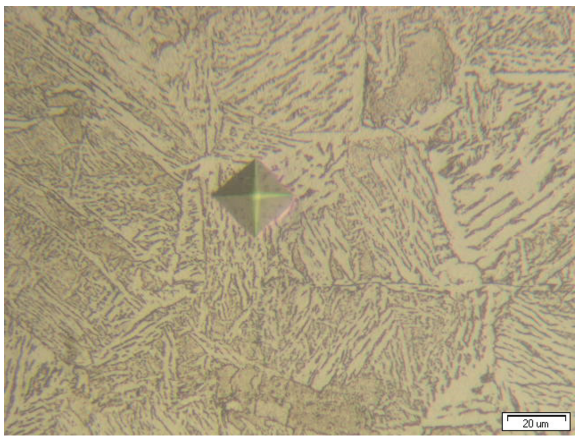
Any technology which joins base material with weld metal brings is not able to prevent the origin of weld undercuts at margins of welding bath, penetrations of foreign matters and oxides. Such areas are very likely to trigger cracks and deformation of the welded metal and initiate electrochemical corrosion.

As it is apparent from Fig. 2, there appear weld undercuts and penetrations of slag resists between the weld metal and base material. The risk of these areas is that they cause early corrosion processes.

## Measurement of Microhardness of Structure Phases (ČSN EN ISO 4516)

Microhardness is one of the basic indicators of structure phases of the material. Chemical composition of the base material influences the most the origin of the individual structure components.

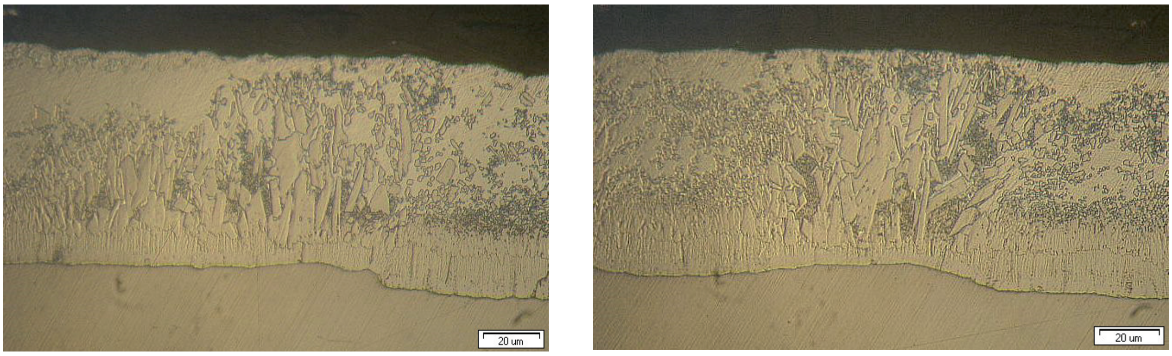
In order to measure microhardness of structure phases of weld metal, heat affected area and base material, Hanneman tester which forms a part of metallographic microscope Neophot 21 was used. There was used the measurement method according to Vickers, principle of which consists in pressing a diamante cone with apex angle of 136° into the



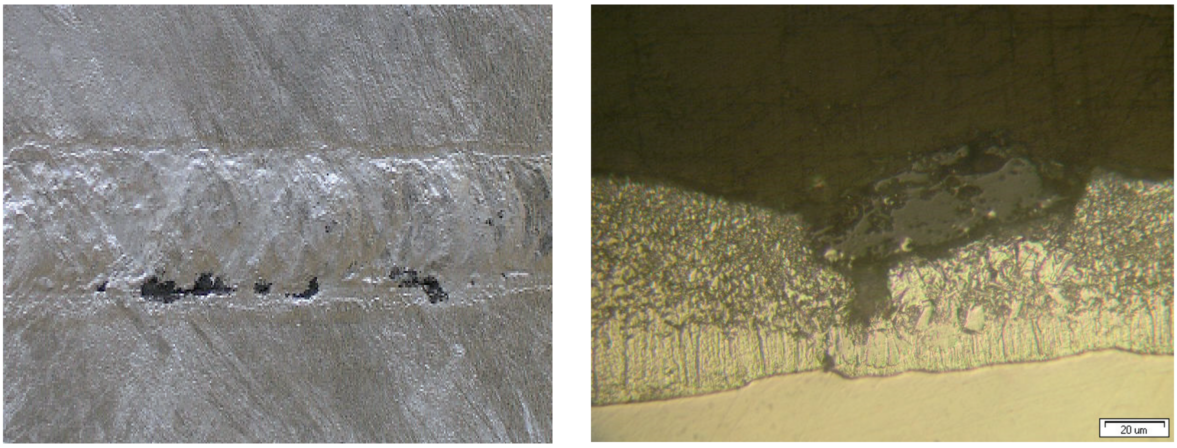

3: *Imprint to the weld metal*

II: *Values of microhardness*

| Measured area | Values of microhardness of the individual areas $HV_{0,25}$ | | | | | |
|---|---|---|---|---|---|---|
| | Measurement (average value) | | | | | Average |
| | **No. 1** | **No. 2** | **No. 3** | **No. 4** | **No. 5** | |
| **Weld** | 270.0 | 273.7 | 269.7 | 270.0 | 266.3 | 269.9 |
| **Heat-affected area** | 258.0 | 292.0 | 297.3 | 255.0 | 282.0 | 276.9 |
| **Base material** | 213.0 | 217.0 | 209.7 | 210.0 | 218.3 | 213.6 |




4: *Intermetallic phases in zinc coating*




5: *Defects of zinc coating*

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

Measurement of microhardness was processed on 3 samples, each of the three tested areas (weld metal, heat affected area and base material) was measured on 5 different places. Average values are written in Tab. II.

Based on the values written in Tab. II it implies that weld is much harder than base material, which results in a potential origin of microcracks in this area.

## Intermetallic Phases in Zinc Coating

There were analysed intermetallic phases of zinc coating which origin as a consequence of diffusion of ferritic ion into zinc coating, see Fig. 4.

Chemical composition of zinc coating:

- zinc corresponds to the chemical composition of the zinc bath,
- phases zeta $FeZn_{13}$,
- phases delta $FeZn_7$,
- phases gamma $Fe_3Zn_{10}$.

Based on an appropriate chemical composition it is possible to achieve such a coating with outweighing pure zinc and phases zeta. The coating is not fragile and is able to better resist to corrosion factors (Votava *et al.*, 2012).

## Zinc-dipping Defects

Before application of any anticorrosion protection, the base material has to be well prepared, that means cleaned, degreased and got rid of any foreign matters. Applying an anticorrosion protection on a welded part, the bigger risk of bad application is reported at the sides of weld bead, where oxides and slag appear during the welding process. If these foreign matters are not removed, this area would be poorly zinc coated (either zinc coat of a poor quality or no zinc coating at all), see Fig. 5 (left). If the part is big in size, application of zinc spray is used for renovation of the defected area.

However, the anticorrosion protection of this place decreases and in most of the cases the electrochemical corrosion commences here. Defected place of a zinc coating is depicted in Fig. 5 (right).

## Advantages of a Zinc Coating

Surface treatment of steel parts using zinc hot dipping is processed in a zinc bath with exactly defined technology which guarantees a homogenous coating of a high quality on the whole machine part. The example is depicted in Fig. 6 (right).

Comparing to the technology of application of paint where the layer applied on problematic sharp edged areas are considerably lowered, zinc hot-dipping technology enables cleaving of zinc in these areas. Practical example is shown in Fig. 6 (left). There is apparent an equal layer of zinc coating and a minimal layer of paint Zinorex.

## Organic Coatings – Paints

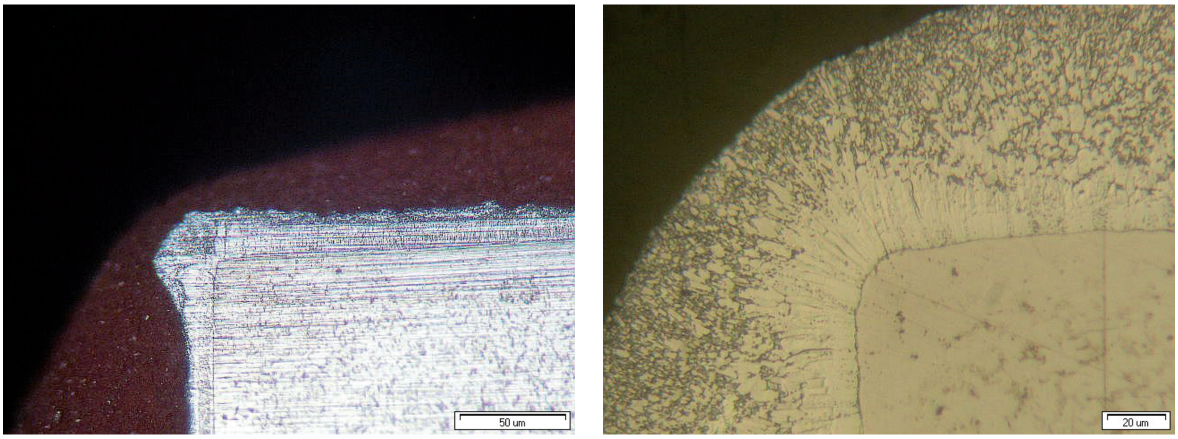
The technology of anticorrosion protection using paints is due to its simplicity often used not only in engineering praxis, but also other fields of industrial or agricultural production. The principle of this technology is to form a protective coating which isolates the metal subject from the environment (Tulka, 2005). Inhibiting pigments which improve the anticorrosion performance of the protective coating for an integral part of it (Ščerbejová, 1993). For the experiment, the following paints were chosen:

- synthetic coating composition (base + top layer),
- acrylate coating composition on zinc coating (duplex system).

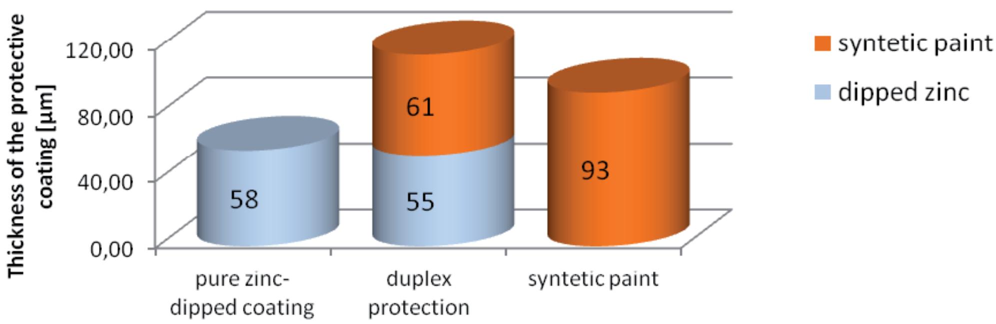
## Assessment of Anticorrosion Coating Thickness

Thickness of the anticorrosion coating is one of the crucial factors affecting the durability of ony anticorrosion protection. Based on their researches, the Association of Czech and Slovakian Zinc Works (Asociace českých a slovenských zinkoven) states, that depending on the environment the corrosion decrease is from 0.64–1.57 μm per year. The thickness of the applied coating is usualy between 30–50 μm, which corresponds to an average value of 0.4–0.8 kg·m$^{-2}$. The minimal durability of zinc coatings can be based on current experiments and current environment conditions estimated at c. 25 years.

In order to measure the thickness of passivating coating, there were prepared metalographic samples. Afterwards, using the computer programme analySIS there was read the value of




6: *Cleaving of anticorrosion coating on sharp edges*




7: *Thicknesses of applied coatings*

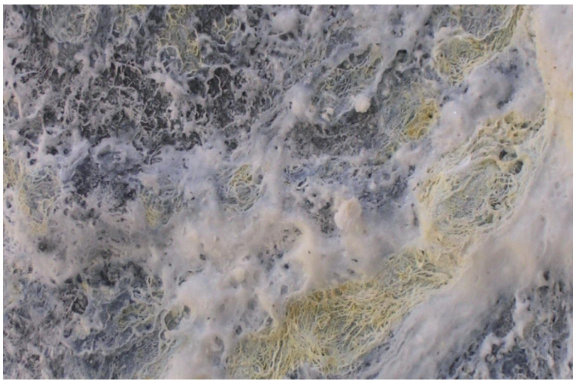
the applied coating with the accuracy of 1 µm. To achieve objective readings, each layer was represented by three samples. Out of each sample 5 readings were obtained and arithmetic average was calculated. Average thicknesses of applied coatings are shown in Fig. 7.

### 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.

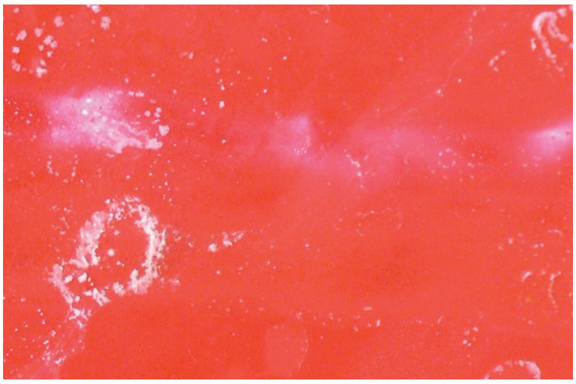
Preparation of samples for testing:

- first of all, there were prepared 20 samples which were welded using MAG method,
- further, anticorrosion coatings were applied on samples (zinc dipping, coating composition spraying),
- afterwards, samples were put into a special stand and were exposed to an aggressive salt spray



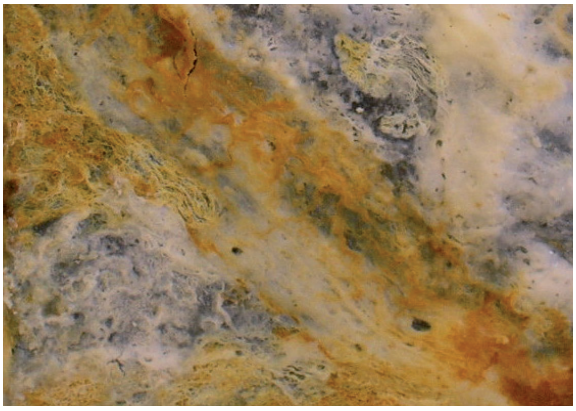
8A: *Weld bead protected by hot dipped zinc*

8B: *Weld bead protected by synthetic paint*

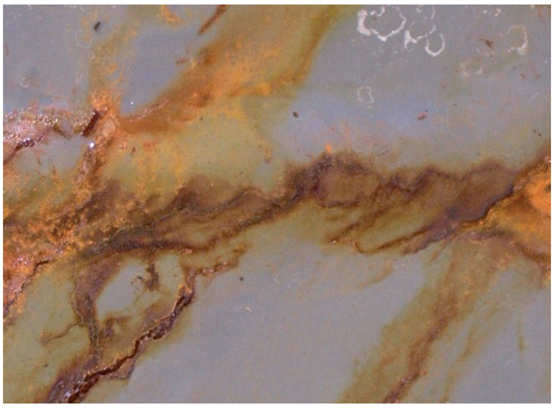


8C: *Weld bead protected by duplex system*

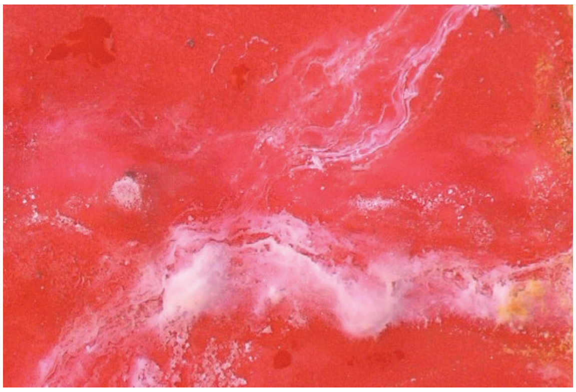
8: *Corrosion degradation of weld beads after application of different protective coatings, samples after 10 days in salt spray environment*



9A: *Weld bead protected by hot dipped zinc*



9B: *Weld bead protected by synthetic paint*



9C: *Weld bead protected by duplex system*

9: *Corrosion degradation of weld beads after application of different protective coatings, samples after 40 days in salt spray environment*

environment. Using visual method, corrosion attack was evaluated made.

Testing parameters:

- temperature in the salt-spray chamber 35 ± 2 °C,
- concentration of the sodium chloride in a spraying medium 50 ± 5 g/l,
- pH value of the salt solution 6.5–7.2,
- the time interval was set for 2, 7, 10, 20 and 40 days. Based on an every-day visual evaluation and depending on the speed of corrosion degradation, the individual intervals may differ.

Resulting from the photo documentation (Figs. 8–9), it can be documented a higher corrosion activity in a heat affected area by the weld bead.

## DISCUSSION

Welding using MAG method belongs to dynamically developing technologies of producing non-dismountable joints. Negative aspect of weld joint consists in heat affected area, in which mechanical resistance as well as impact resistance drops. In the area of weld undercuts, there is a higher risk of early corrosion degradation (Hazlinger *et al.*, 2010).

Practical experiment is focused on an overall monitoring of weld joints produced by the MAG method, their anticorrosion protection which would be useful not only in the field of supporting frameworks but also in the whole engineering praxis. Base material used in the experiment was steel S235JR (well-weldable material). Based on the metallographic observation, each of the weld beads shows a good quality. In order to evaluate weld metal, there was also measured microhardness of the heat affected area and chemical composition of weld metal. An area with higher risk of corrosion origin identified – which is an area of weld undercuts next to weld beads. There was created a microstructure with higher potential of internal energy; according to the EDS method there also rises the amount of oxygen ($O_2$).

In order to observe the corrosion degradation under the conditions of salt spray test, both inorganic (zinc dipping) and organic (synthetic coating composition) protections were used. Low anticorrosion protection of hot dipped zinc coating as well as the influence of negative factors (such as $O_2$, microstructure) on origin of corrosion attack were proved. The influence of negative factors is obvious at the synthetic paint after 10-day test, when point corrosion in the weld undercuts of weld beads is reported. Best results are achieved by duplex system, which after 40-day test show only corrosion products of the zinc coating.

## CONCLUSION

Corrosion degradation of technical materials is an irreversible process, which results in a gradual destruction of the whole machine part. Even though welding belongs to the most widely used production technologies of fixed joints, it has to be stated that there occurs a partial degradation of base material. This statement was proved by processed metallographic scratch patterns as well as EDS. It is mainly about the change in structure in the heat affected area. Weld undercuts and teeth at the edges of weld bead are also apparent. Later, such places may initiate cracks in the material.

As during the welding process a lot of energy is brought to the material, it can be supposed that the corrosion pressure on weld metal will be increased. The photo documentation of this paper monitors the process of corrosion degradation of individual protective coatings applied on materials welded by MAG method in the salt spray environment. Zinc coating performs a gradual degradation on the whole surface, which is caused by a low anticorrosion resistance of zinc against salt ions. Samples treated by synthetic system have shown an early corrosion in the area of weld undercuts. The best result was achieved by duplex system: there was observed just a minor attack of corrosion products of zinc hydroxide.

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