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EFFECT OF PLASMA HARDFACING AND CARBIDES PRESENCE ON THE OCCURRENCE OF CRACKS AND MICROCRACKS

UTICAJ NAVARIVANJA PLAZMOM I PRISUSTVA KARBIDA NA POJAVU PRSLINA I MIKROPRSLINA

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Keywords
- plasma welding
- hardfacing
- carbides
- cracks
- microstructure

Abstract

Presented is the effect of plasma hardfacing (or just hardfacing) and carbides presence on the occurrence of cracks and microcracks in the welded layer. The reasons behind this phenomenon are analysed and explained. In addition, the plasma welding technology with all the necessary data such as welding parameters is shown for the case of undamaged tooth of a machine used for the milling of marble. The welded layer with a significant amount of tungsten-carbide is applied onto new, undamaged tooth in order to improve the characteristics of the surface layer of the base material by increasing its hardness which leads to increasing of wear resistance and impact toughness. After welding, the tooth is cut using electrical discharge machining (EDM) for examining the applied surface layer in different locations throughout the welded joint. Macro and microstructural analysis aided in determining the characteristics of the surface layer. The nature and causes of cracks and microcracks are analysed in order to provide a better solution to avoid crack occurrence, as well as in determining their potential effect on the integrity of the tooth as a whole.

Ključne reči
- zavarivanje plazmom
- tvrdo navarivanje
- karbidi
- prsline
- mikrostruktura

Izvod

U radu je prikazan uticaj navarivanja plazmom (tvrdog navarivanja) i prisustva karbida na pojavu prslina i mikroprslina u navarenom sloju. Analizirani su i objašnjeni uzroci koji su doveli do ovog fenomena. Pored toga, prikazana je i tehnologija zavarivanja plazmom, sa svim neophodnim podacima poput parametara zavarivanja, za slučaj neoštećenog zuba mašine za mlevenje mermera. Navareni sloj koji sadrži veliku količinu volfram karbida je nanesen na novi, neoštećeni zub kako bi se poboljšale osobine površinskog sloja, povećavanjem njegove tvrdoće, čime se povećava i otpornost na habanje, kao i udarna žilavost. Nakon zavarivanja, zub je isečen erozimatom za potrebe ispitivanja navarenog površinskog sloja u različitim oblastima zavarenog spoja. Analize makro- i mikrostrukture su izvršene kako bi se odredile osobine površinskog sloja. Priroda i uzroci pojave prslina i mikroprslina su takođe analizirani, kako bi se pronašlo bolje rešenje za njihovo izbegavanje, kao i u cilju određivanja njihovog potencijalnog uticaja na integritet zuba kao celine.

INTRODUCTION

Hardfacing refers to technologies used in order to apply an additional layer that protects against wear, corrosion, erosion, or to restore dimensions reduced by wear /1-3/. This technology is originally applied for the purpose of repairing reduced or damaged dimensions, which in some cases lead to significant savings /4/.

Meanwhile, the use of hardfacing has expanded to protecting new machine parts and tools by applying new materials with significantly improved characteristics. Improvement of surface characteristics is a specific technological problem that involves material science, base- and weld material properties, as well as phenomena that occur during this process, such as cracks, which overall affect the integrity of the machine part subjected to hardfacing.

Due to the hardfacing process, occurrence of cracks represents a significant problem and as a result of molten material contraction the risk of cracks occurring increases in the case when hard materials are used. In some cases, cracks in the welded layer may propagate into the base material as well.

In addition to the adequately selected welding technology, it is necessary to select the appropriate additional material. The effect of alloying elements in the additional material plays a significant role, and the selection of this material depends on the type of damage, i.e. the function of the workpiece, /4-8/. For the purpose of increasing wear resistance, additional materials used nowadays have an increased carbide content which improves the hardness of the welded layer, but also increases the risk of cracks, as mentioned above.

Shown in the following section is the plasma welding technology used for a new, undamaged part. The case involves hardfacing of the tooth of a machine used for marble milling. A 6 mm thick layer is welded onto the tooth in order to increase its wear resistance. After the hardfacing process, macro and microstructural analyses of individual sections of the welded layer are performed in order to determine the welded layer structure and the cause and effects of cracks and microcracks. The goal of this study is to investigate and analyse the effect of plasma welding on an experimental level, with particular focus on the welded layer thickness, occurrence of cracks and their distribution.

WELDING (HARDFACING) TECHNOLOGY

Hardfacing represents the process of obtaining an inseparable connection between the base- and the welded layer, achieved by melting and softening, with or without pressure. Before the immediate hardfacing process, activities should be undertaken in accordance with general repair algorithms /9/. In short, it is necessary to adopt a hardfacing plan which includes the following activities:

- adopting a hardfacing method,
- preheating (if necessary),
- selection of additional material,
- applying the bonding layer,
- determining the number of passes and layers,
- determining the technological welding parameters,
- additional heat treatment (if necessary).

Plasma is an electrically conductive, dissociated and highly ionized gas, i.e. an intensified electric arc. Plasma arc is created inside a special plasma burner – plasmatron, which consists of an electrode, a nozzle and an insulator placed between them. Power is supplied using direct current, wherein the electrode acts as a cathode, and the nozzle or the workpiece act as the anode. Electric arc is established between a water-cooled tungsten electrode and the workpiece, and is narrowed using a copper nozzle, also water-cooled. Narrowing of the arc is an important aspect of plasma welding, as it achieves a better distribution and higher temperature compared to the related TIG procedure.

When choosing a gas or gas mixture for plasma, atomic and specific masses should be taken into account, along with the thermal conductivity coefficient, ionization energy and nature of the gas. Thermal conductivity is of particular importance due to the heat transferred to the workpiece.

The most commonly used plasma gas is highly pure (99.95 %) argon (Ar), since it is cheaper than other gases and does not cause any metallurgical problems, and has low ionization energy, which enables quick and safe establishing of an electric arc for idle voltage below 100 V.

Applying a protective layer to the tooth by plasma is performed using Eutectic Castolin company equipment (Fig. 1). Pure argon is used as a shielding gas, whereas a mixture of argon and hydrogen is used as the plasma gas.

EuTroLoyPG 6503 powder is used as additional material, manufactured by Castolin /10/. The powder consists of Ni-B-Si-Fe alloy with 60 % tungsten carbide. This powder forms a surface layer of 60 HRC hardness, /10/, providing high resistance to wear in the applied surface layer.

Figure 1. Equipment used for plasma welding.

The base metal of the tooth is 25CrMo4+QT (according to DIN standard). It is a low-alloyed steel with QT designation – delivered in tempered and relaxed state (quenched and tempered - QT), /11/. Chemical composition of this material is given in Table 1. This steel is a heat treatable alloyed steel with a typical tensile strength of 700-950 N/mm² with good weldability, generally used for automotive and aircraft components with high toughness as axles, axle journals, turbine parts, turbine rotors. Hardness of this steel is approximately 20 HRC, /11/.

Table 1. Chemical composition of steel 25CrMo4+QT.

Chemical elements	C	Si	Mn	P_{max}	S_{max}	Cr	Mo
% by mass	0.22-0.29	0.40	0.60-0.90	0.025	0.035	0.90-1.20	0.15-0.30

In order to achieve a stronger bond between the welded layer and the base metal, the workpiece is preheated using gas flame, with a temperature of about 130°C.

Plasma welding process itself is performed in seven passes, wherein each pass has three layers so that the desired thickness of 6 mm can be achieved. Width of each pass is 20 mm. They were aligned in such a way that each layer is displaced by from the previous one in order to ensure overlapping of 2-3 mm for the purpose of better compliance with the workpiece contour. Shown in table 2 are the welding parameters for each pass with information about amperage, welding speed and position.

Table 2. Welding parameters for different passes.

Pass number	1.	2.	3.	4.	5.	6.	7.
Current amperage [A]	80-100	80-100	80-100	80-100	80-100	80-100	80-100
Welding speed [mm/s]	0.5-0.55	0.55-0.65	0.65-0.70	0.70-0.80	0.80-0.90	1	2.6
Welding position	90º	73-75º	73-75º	73-75º	73-75º	40º	15º

Figure 2 (left) shows a tooth before and after hardfacing procedure. Shown in Fig. 2 (right) is the tooth welding plan. A layer with a thickness of approximately 6 mm is welded onto this tooth. Total weight of the welded layer is 3.5 kg.

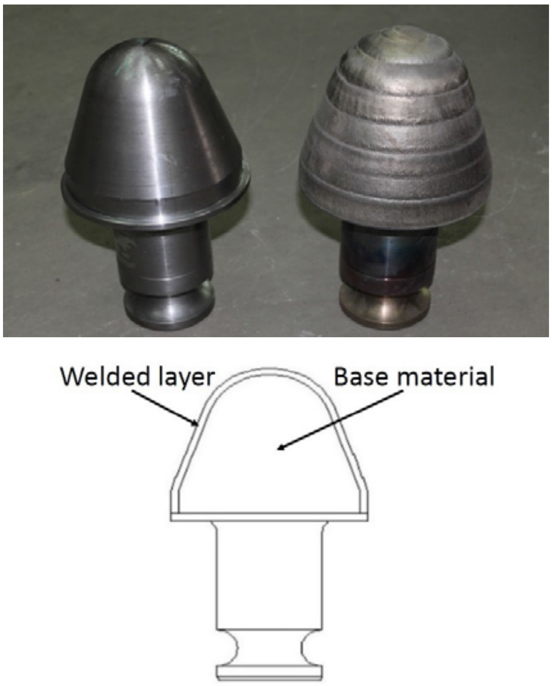


Figure 2. Tooth appearance before (left) and after hardfacing (right). Tooth welding plan with the welded layer (bottom).

TEST RESULTS

For the purpose of determining the welded surface layer structure (welded layer), macro- and microstructural analyses are performed. For this purpose, the whole tooth is cut longitudinally into two halves using the EDM machine after the hardfacing. The appearance of one-half of the tooth after cutting is shown in Fig. 3. According to rough measuring, the layer thickness varied from 3 to 7 mm.

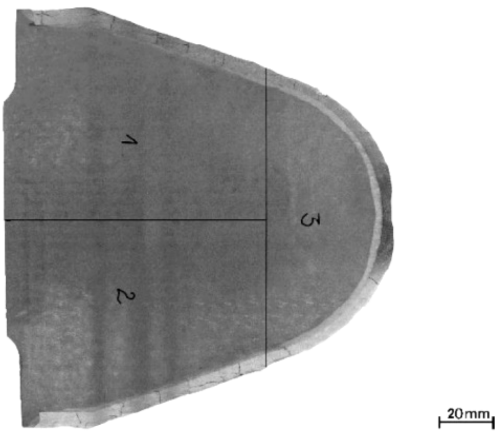


Figure 3. Appearance of the cut tooth, with zones 1, 2 and 3.

Investigations of the macro- and microstructure are performed in sections A, B and C of the cut part (Fig. 4). Zone A includes the tip of the tool, whereas zone B is located on the lateral side of the tooth within zones 3 and C located on the lateral side of the tooth within zone 1.

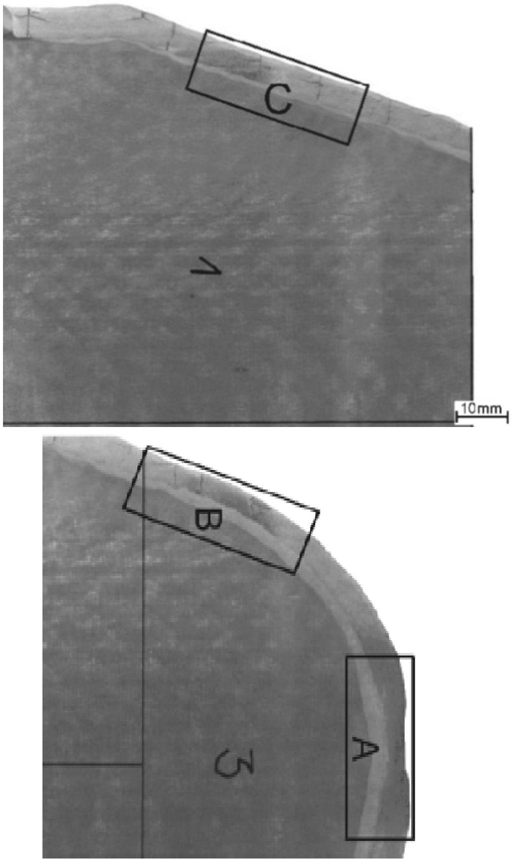


Figure 4. Review of sections (micro-sections) A, B and C where structural tests were performed.

Shown in Figs. 5-7 are the structures of the welded layer on the macro level for sections A, B and C. Welded layer thickness ranged from 3.1 mm (at the tip of the tooth, as can be seen in Fig. 6) to 6.4 mm in the curved part of the tooth. Due to high element particle density, the welded layer structure appears quite uniform. Figure 5 shows section A, wherein a small quantity of tungsten carbide can be seen. In other zones (Figs. 6 and 7), a larger amount of tungsten carbides can be observed, along with the geometry and distribution of cracks. Figure 6 shows the structure of section B. Observed cracks are located in the welded layer itself and their fragmentation can be seen. In Fig. 7, the structure of section C can be seen. Macroscopic cracks observed in the cross-sectional layer spread in radial in tangential directions and are relatively uniformly distributed. Cracks do not occur in the base material, but only in the welded layer itself. Microcracks are observed on the border between the hard weld and the base metal (Fig. 8).

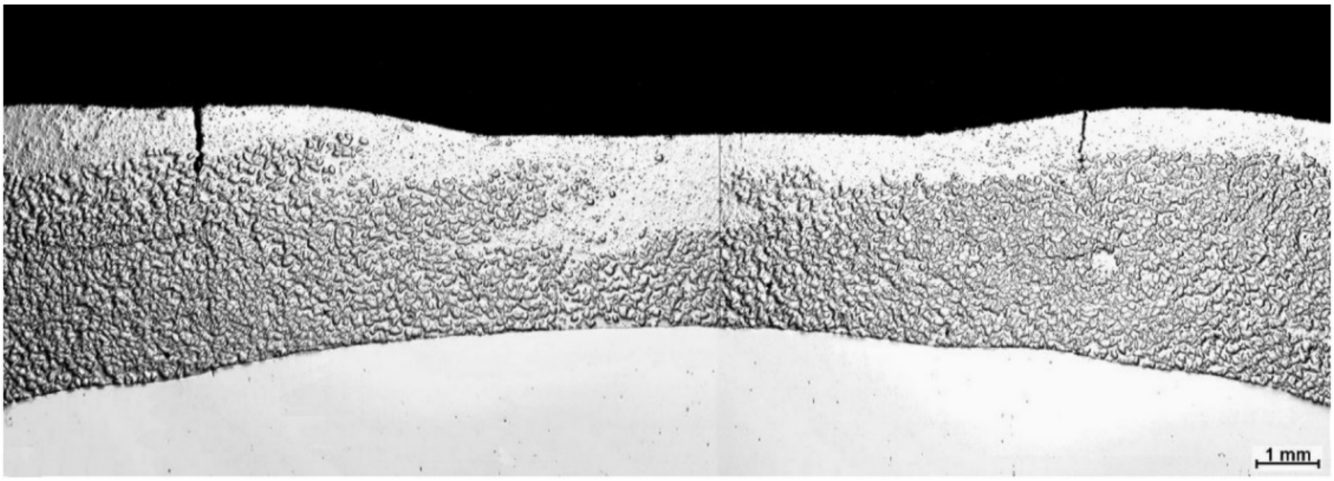


Figure 5. Section A: small distribution of tungsten carbides on the tooth tip and the appearance of microcracks.

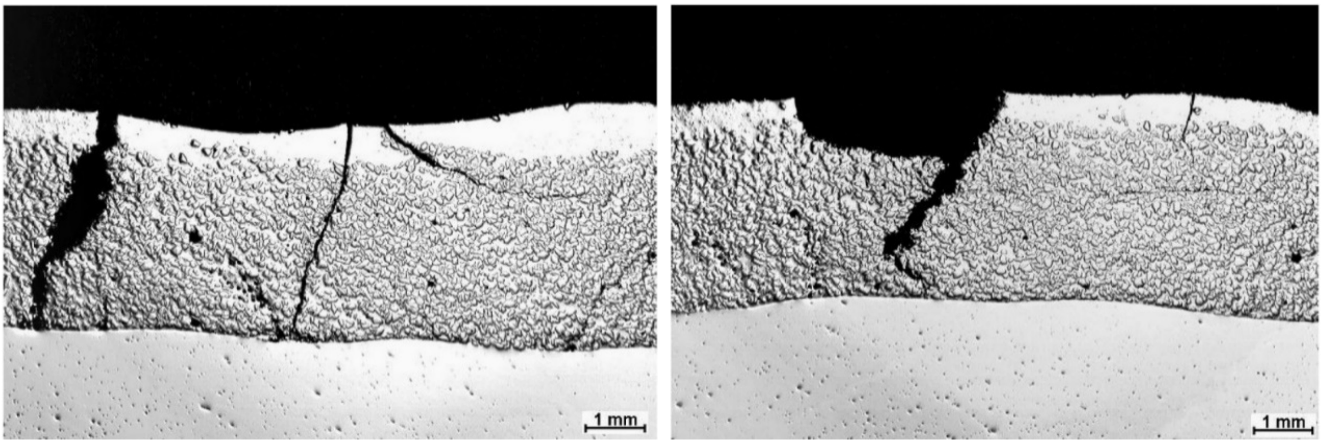


Figure 6. Section B: distribution of tungsten carbides and crack propagation (left); observed cracks and fragmentation (right).

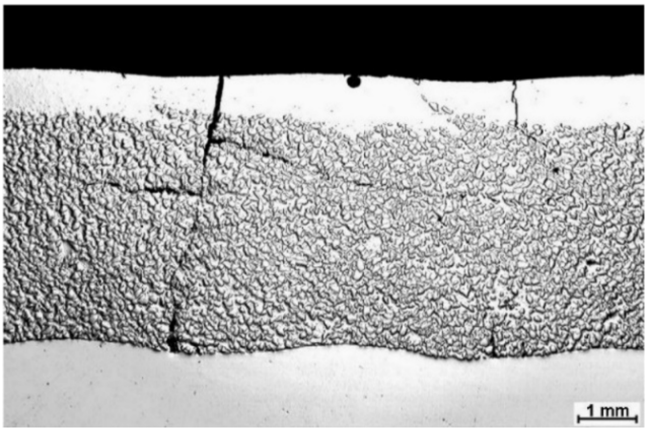
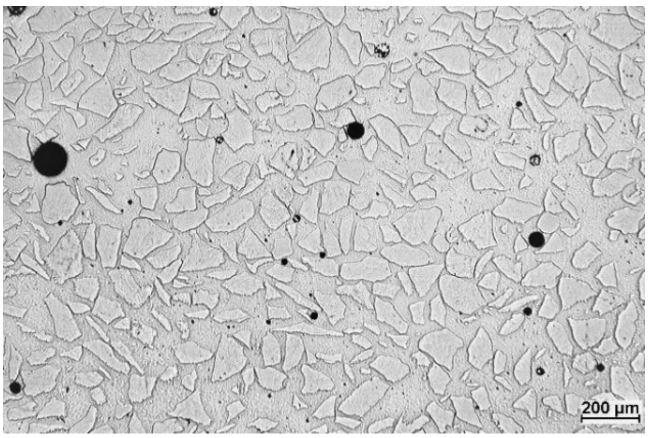


Figure 7. Section C: distribution of tungsten carbides and crack propagation.

Shown in Figs. 8 and 9 are the microstructures of section B. A large amount of carbides can be observed in these figures as well. Microscopic analysis determined that the cracks located in the surface layer, i.e. the weld with mostly pass-through tungsten carbides (Figs. 8-bottom and 9). In addition, a non-uniform distribution of oxides can be observed in the compacted metal pores of varying size (with maximum diameter of 100 micrometers). The welded layer micro-structure is made of light metals with a dendrite structure and a large amount of tungsten carbides, whose structure is needle-like (Figs. 8-bottom and 9).



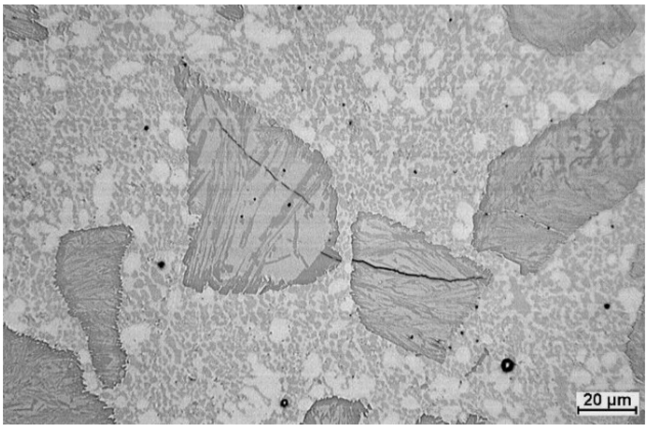


Figure 8. Section B: microstructure and distribution of tungsten carbides and pores (top); crack propagation in tungsten carbide (bottom).

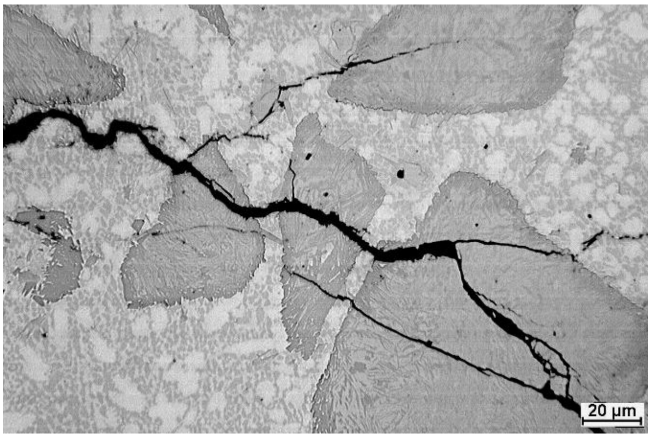


Figure 9. Section B: crack propagation

CONCLUSIONS

Presented technology of hardfacing of a tooth used for marble milling via plasma technique represents one of the methods which have an aim to improve the characteristics of the surface layer. In this specific example, the primary goal was increasing wear resistance of the tooth by applying a hard coating which contains a considerable amount of tungsten carbides. The presence of tungsten carbides increases hardness, but also increases the brittleness of the welded layers, thus the risk of crack and micro-crack occurrence is higher. This can be explained by the temperature differences that occur during the hardfacing process due to a large temperature gradient between the molten metal and base material. Rapid cooling leads to rapid contraction of the molten material which results in strain, cracks and micro-cracks. Micro-structural analysis of the sections had determined that cracks have propagated throughout the welded layer, i.e. they mostly pass through tungsten carbides. These cracks and micro-cracks can further propagate (especially in case of fragmentation), thus increasing the rate at which the welded layer and base material degrade, in the case that the crack propagates. Strain and cracks can be reduced by applying an intermediate layer, also known as the "buffer" layer, which acts as an elastic connection between the hard weld and soft base material. This layer can also prevent further crack propagation from the weld layer to the base material. In addition, for the purpose of further investigation of the effects of this hardfacing method, the tooth should be tested after it has been exploited for a specific period of time.

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