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HEAT AFFECTED ZONE IN SURFACING CHROMIUM LEDEBURITIC STEEL

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Tools get failured during work; wear is a major factor that contributes to failures. Damaged tools are replaced or filed. This paper describes typical changes that occur in the heat affected zone of tool (HAZ), which was repaired by surfacing with a TIG and with micro-plasma procedure. Microstructure of the steel on the repaired tool was analysed by an optical and scanning electron microscope. The tool was made of chromium ledeburitic steel type W.N. 1.2379 and it was repaired by surfacing steel type W.N. 1.4718. Changes in the HAZ also depend on the type of surfacing. Besides microstructural changes, dissolution of carbides, especially primary carbides. This way the concentration of the carbide-forming elements and carbon is increased in the base around the primary carbides in the HAZ so the result is so-called secondary eutectic or secondary ledeburite.

Key words: repair welding, heat affected zone, microstructure, carbides, dissolution, secondary ledeburite

Zona utjecaja topline kod navarivanja kromovog ledeburitnog čelika. Alat se tijekom rada oštećuje. Većina oštećenja nastaje zbog habanja materiala. Oštećeni alat se popravlja navarivanjem. U ovom radu opisuju se značajne promjene u zoni utjecaja topline (ZUT) alata koji je obnovljen navarivanjem TIG postupkom i mikroplazmom. Mikrostrukturu čelika obnovljenog alata analiziralo se pomoću optičkog i scaning elektronskog mikroskopa. Alati su izrađeni iz kromovog ledeburitnog čelika W.N.1.2379, a obnovljeni su navarivanjem čelika W.N.1.4718. Promjene u zoni utjecaja topline povezane su također i s načinom navarivanja, među mikrostrukturnim promjenama specifično je rastapanje karbida, posebno primarnih. Na takav se način u okolini karbida u ZUT povećava koncentracija karbidotvornih elemenata i ugljika toliko, da dolazi do lokalnog taljenja i nastanka t.z. sekundarnog ledeburita.

Ključne riječi: reparaturno zavarivanje, zona utjecaja topline, mikrostruktura, karbidi, lokalno taljenje, sekundarni ledeburit

INTRODUCTION

Repair welding is not used enough in the industry [1]. One of the reasons for this lies in the insufficient and unrealiable knowledge in many segments of this area. A very important part is having appropriate knowledge of metallurgical processes in heating of the base material [2-4]. Unsuitable heating deteriorates the microstructure as it reduces toughness and fracture behaviour of the weld [5].

We observed the changes in the HAZ of surfacing welds produced by the TIG and micro-plasma process. By surfacing we were repairing the cutting tools [6] made of the cold work chromium ledeburitic steel.

Tool steels are very demanding for surfacing [7-11] as they tend to crack. That is why they need to be preheated and are cooled off slowly after the welding process. For a long time manual arc welding was the most important process for repair welding of tools but now it is becoming less important because the coated electrodes are difficult to weld with in low current intensity which is very important in surfacing the smaller tools or cutting edges. It can be reached with a TIG process which was used for repairing the tools. Micro-plasma welding which is similar to TIG process is also often used. The difference is in the fact that the arc of the plasma is more narrow and the energy more concentrated [12-15]. Laser surfacing has also become very efficient and important for repairing tools.

EXPERIMENTAL WORK

We made two different specimens. One of the surfacing welds was made with the process of micro-plasma surfacing while the other was made with the TIG process. Table 1 shows the chemical composition of steel for tools and filler material. Based on the chemical composition of tool steels (base material) we chose the temperature of preheating and type of filler material. The preheating temperature was 400 ^{o}C and was controlled with a thermocouple Ni - NiCr. We carried out the preheating in the electric resistance furnace.

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Table 1 **Chemical composition of the steel of base and filler material**

Type of material SIST EN 10027 – 2	chemical composition / wt. %							
	C	Si	Mn	P	S	Cr	Mo	V
Workpiece: 1.2379	1.55	0.4	0.35	0.03	0.03	12	0.8	0.9
Filler material: 1.4718	0.5	2.9	0.8	0.04	0.03	9	/	/

Table 2 **Hardness of steel base material, HAZ and weld**

type of welding	place of hardness measurements / HV							
	Base material		HAZ					Weld
	Middle	Close to HAZ	Point 1	Point 1/1	Point 2	Point 3	Point 4	
Micro-plasma	701	732	874	918	909	833	726	441
TIG	709	746	830	867	707	593	441	374

After the welding process the surface welds were forged and then annealed at the temperature of 400 °C. This way we removed part of the internal stresses in the surface weld. Cooled workpieces were then grinded. Thus prepared workpieces became useful for work in production. Based on the colour on the surface of the workpieces we determined that the area of the heated base material (HAZ) was wider in surfacing by TIG process because there is more energy put into the workpiece than by the micro-plasma welding. In order to determine what is happening in the HAZ we measured the hardness on the cross sections of the produced specimens. Specimens were investigated with optical (OM) and scanning electron microscope (SEM), microstructure was analysed and the typical areas of microstructure were microanalysed. The trail of hardness across the HAZ of both surface welds is in Figure 1. Hardness of the base material is around 700 HV. In HAZ the hardness increases over 900 HV from the fusion line to weld.

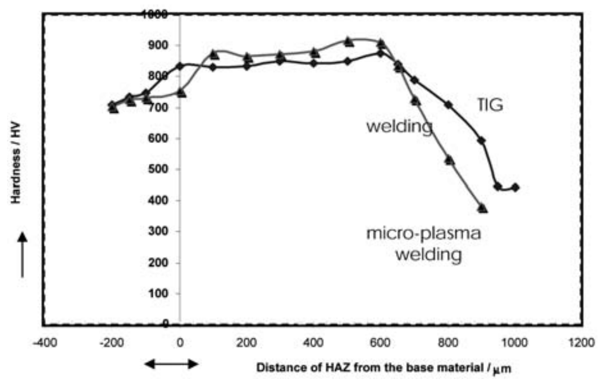

Figure 1 The trail of hardness profile across the HAZ of both surface welds

Based on several measurements we determined the middle values of hardness in particular parts of the surface weld, such as: hardness of the base metal, hardness of the HAZ and hardness of the weld. This data is in table 2. Table 2 shows that the hardness values in welding with micro-plasma in the HAZ are sistematically higher. Figure 1 shows that the width of the HAZ for surface welding with micro-plasma (710 μm) is smaller than in surface weld achieved with TIG (950 μm).

RESULTS AND DISCUSSION

Different procedures of repair welding are used to maintain tools, such as: manual arc, TIG, micro-plasma, electroimpulse, laser welding etc. Our work focused on TIG and micro-plasma welding. We made the specimens which were analysed with the optical and scanning electron microscope. Figure 2a shows the macrostructure of the specimen welded with a micro-plasma, Figure 2b shows the macrostructure of the specimen welded with a TIG process. In macrostructure the area of the weld (cast), of the HAZ and of the base material are differentiated.

Steel that was welded (base material) was quenched and tempered. Microstructure of the steel consists of the tempered martensite and carbides. In particular parts of the surface weld we analysed the microstructure areas and differences of chemical composition in various microstructural components. Analysed areas are marked with numbers from 0 to 4 in Figure 2.

Analysis of the HAZ of steel surfaced with micro-plasma

Measurement results of micro-analysis of specimen prepared with micro-plasma welding can be seen in Figure 3. Figure 3a is a microstructure on the cross-point from the base material into the HAZ, and Figure 3 b) shows the microstructure in the hot part of the HAZ close to the cross-point into the weld (fusion line). The hot part of the HAZ is the part of the HAZ near at the weld (fusion line), while the cold part is on the border with the base material.

Figure 4a shows partially dissolved of the primary carbide in the hot area of HAZ, about which form secondary ledeburite. This carbide was componente of the

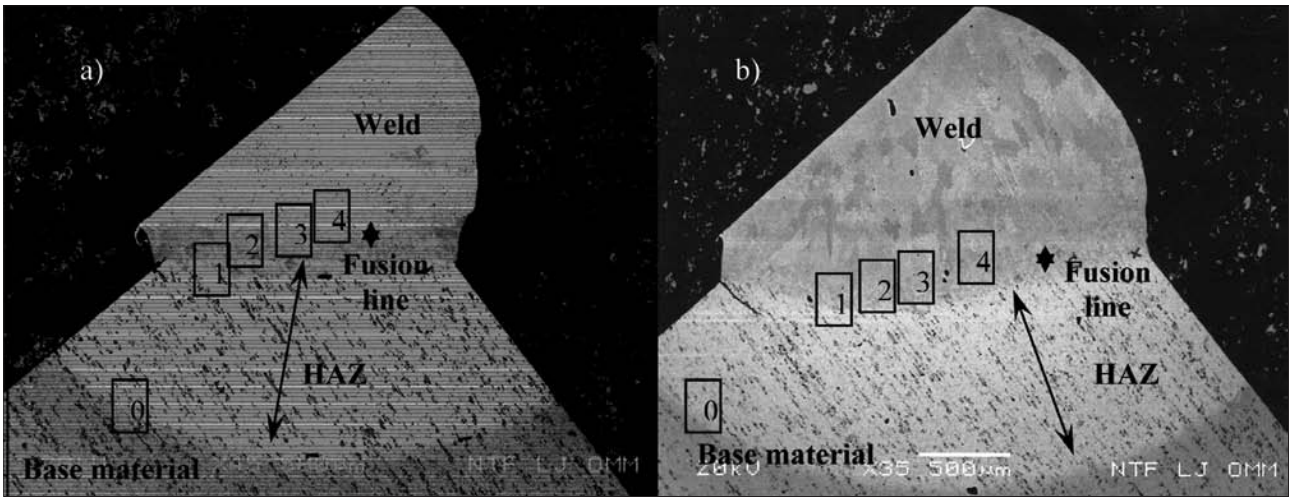

Figure 2 Macrostructure on the cross section of the surface weld on the steel tool; a) micro-plasma, b) TIG; SEM, BSE (image of back scattered electrons)

Table 3 **Chemical composition of steel surface weld prepared with micro-plasma welding (Figure 2a)**

ANALYSIS POINT	CHEMICAL COMPOSITION / wt. %					
	Fe + C	Si	Mn	Cr	V	Mo
Base material (point 0 – base)	Rest	0,5	0,42	5,18	0,05	0,22
HAZ close to the fusion line (point 1 - base)	Rest	0,12	0,26	5,8	0,11	0,12
Middle of fusion line (point 2, 3 – base)	Rest	0,09	0,44	7,3	0,14	0,14
Cross-point of fusion line/weld (point 4 - base)	Rest	0,16	0,44	7,5	0,09	0,11

primary ledeburite which formed at steel solidification (of the base material) and which got a typical semi-elliptical form during hot working and was formed as a result of local fracture of the bigger carbide whose parts were distributed by the matrix during the deformation of steel [16].

Microstructural components are normally formed in the HAZ which are result of solid state transformations. In the hot part of the HAZ a local three steps transformation (solidus – liquidus – solidus) occured and it resulted in rings of secondary ledeburite around big partly dissolved primary carbides. The microstructure of the middle part of the weld shows big crystal grains of austenite (at the temperature of its origin, now martensite) while there is ledeburite eutectic distributed on its borders. EDXS analysis of the mentioned part (points 2, 3) showed increased value of chromium in the base. It increased in the weld (point 4) to 7,5 wt. % (Figure 4b).

Microstructure of surface weld preparing by the TIG process

EDXS analysis of the specimen welded by the TIG process (table 4) shows that in this case there also occurs incipient fusion in the area of primary carbide parts on the hot side of HAZ. Microstructure and microchemical

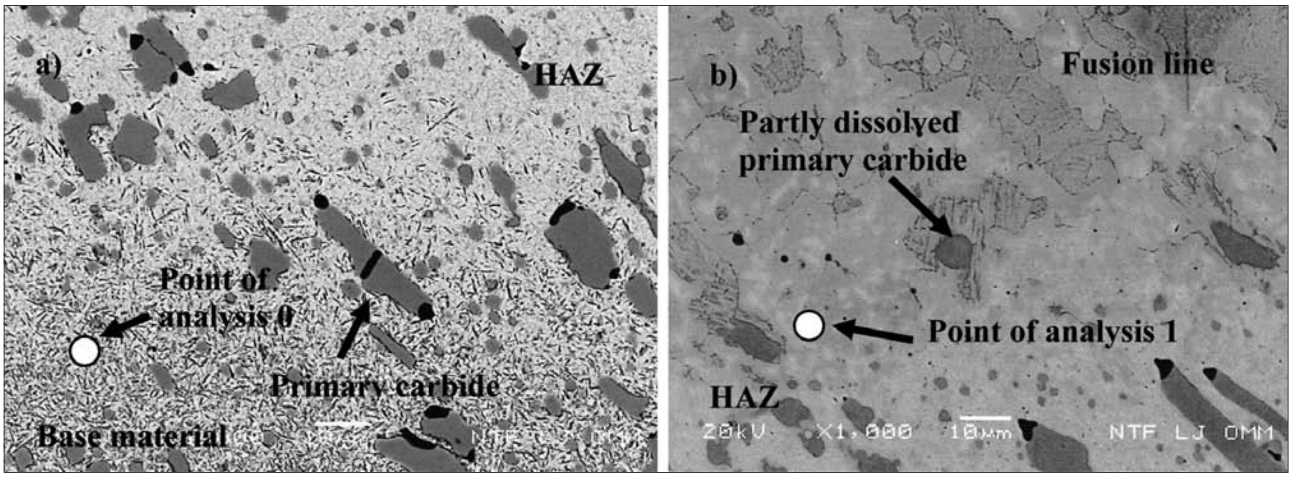

Figure 3 Micro-plasma surfacing: a) microstructure at the cross-point base material (bottom) / HAZ (top), b) microstructure of the hot part HAZ (top) close to the cross-point into the weld, SEM; BSE

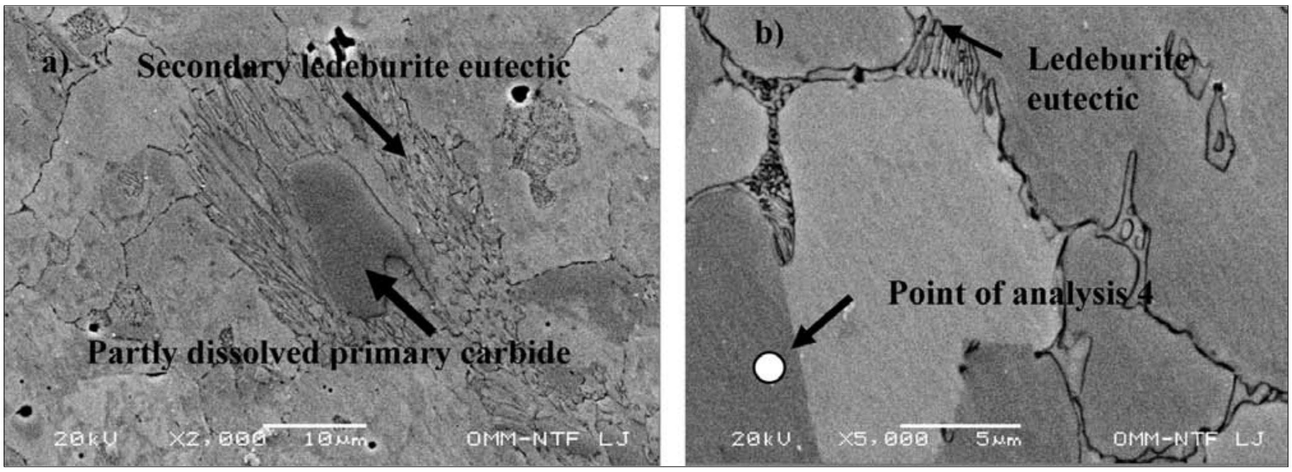

Figure 4 Micro-plasma surfacing: a) microstructure of the partly dissolved primary carbide and its area in the hot part of HAZ; b) microstructure of the weld; SEM; SEI

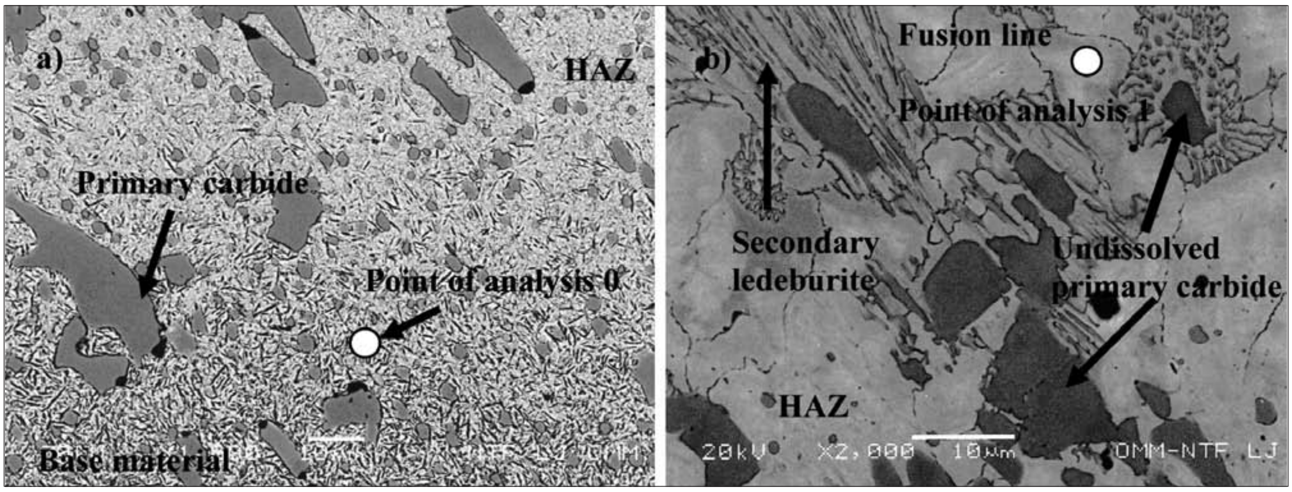

Figure 5 Surfaced by TIG process: a) microstructure at the cross-point base material / HAZ (top), b) microstructure at the cross-point of HAZ / fusion line: SEM; SEI

changes in the area of primary carbides in HAZ are the same as the changes in micro-plasma welding. Figure 5a shows the microstructure at the cross-point from the base material into the HAZ (cold part), while figure 5b shows the cross-point into the hot part of HAZ.

Distribution of elements in the area of partly dissolved primary carbide (Figure 6) is the same as the distribution in figure 4: the area of dissolving primary carbide is enriched with chromium and carbon to the point of concentration where the secondary ledeburite is formed. Figure 7a shows the microstructure of the weld. We measured the chromium content in the matrix with microanalysis and it was 8,3 wt.% Cr. Microprint of the partly dissolved primary carbide surrounded with secondary ledeburite on the hot side of HAZ can be seen in figure 7b. Through a part of the secondary ledeburite (figure 7b), we measured the local iron and chromium concentration with a line analysis. We measured the chromium content in the steel matrix (point 4) which was 8,3 % (measured with the EDXS).

Both types of surfacing ledeburitic steel cause HAZ to occur. However, HAZ was wider by surfacing with TIG. In both cases we observed local incipient fusion in

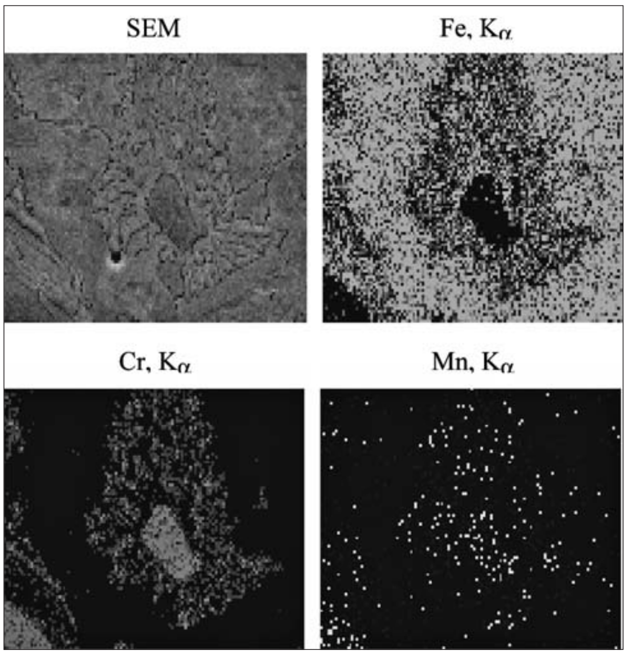

Figure 6 Surfacing by TIG: distribution of iron, chromium and manganese in the area of partly dissolved primary carbide in the secondary ledeburite in the hot part of HAZ; SEM; EDXS

Table 4 **Chemical analysis of steel surface weld made by the TIG process (Figure 2b)**

ANALYSIS POINT	CHEMICAL COMPOSITION / wt. %					
	Fe + C	Si	Mn	Cr	V	Mo
Base material (point 0 - base)	Rest	0,13	0,37	5,42	0,09	0,15
HAZ close to the fusion line (point 1 - base)	Rest	0,10	0,30	7,6	0,09	0,12
The middle part of fusion line (point 2, 3 – base)	Rest	0,14	0,46	8,3	0,07	0,11
Cross-point of fusion line/weld (point 4 - base)	Rest	0,17	0,16	8,3	0,11	0,12

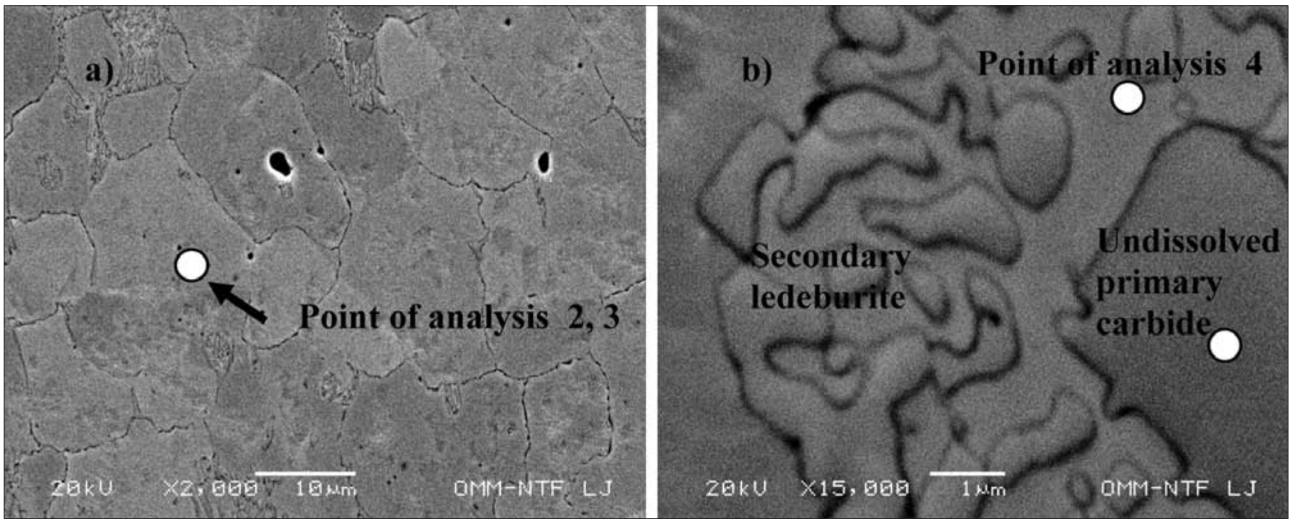

Figure 7 Surfacing by TIG: a) microstructure of the weld, b) partly dissolved primary carbide with a secondary ledeburite, SEM; SEI

the hot side of HAZ at the border of weld (fusion line) in the areas of big primary carbides which resulted in occurance of secondary ledeburite around the partialy dissolved primary carbide. There are separated or connected spots of secondary ledeburite around the partialy dissolved primary carbides and unchanged matrix of HAZ.

Appearance of secondary ledeburite can be explained as a result of local incipient fusion of austenite next to the primary carbides in which they completely or partly dissolve and we get a melt, which solidified locally in the form of secondary ledeburite. The area of the primary carbide also becomes enriched with chromium and carbon to the concentration point at which an alloy is formed. This alloy has a melting point lower than the melting point of steel base (austenite) or lower than the actual temperature in that part of HAZ. Thus this formed alloy solidified into the secondary ledeburite.

CONCLUSIONS

With the process of surfacing by TIG and micro-plasma we made metalurgically quality surface welds on the chromium ledeburitic steel OCR12 VM (W.N. 1.2379) tool with all the elements that are characteristic of welding procedures: weld, heat affected zone and base material. HAZ was narrower at the micro-plasma welding than at the TIG, while the hardness in HAZ at TIG process is lower than in surfacing with micro-plasma. In both cases we discovered an area of local melting of steel around the primary carbides in the hot part of HAZ next to the weld. The area of primary carbides solidificated in the form of secondary ledeburite.

Microstructure of the weld consists of dendrites of austenite and ledeburite eutectic. The boundary between the weld and HAZ is made of many branches with independent or connected spots of secondary ledeburite around primary carbides. The cause of such morphology is local dissolution of carbides and melting of the steel (austenite) next to the primary carbides while in this newly occured melt the carbides melt relatively fast and it comes up to the melt of ledeburite chemical constitution.

The border between the welds and HAZ fusion line is normally evenly joined in the weld (surface deposit) in such a way that HAZ doesn't cross that line into the weld and also the weld doesn't cross over into the HAZ. In this case the border is undefined as there are some independent or connected spots of melt around the big primary carbides in the hot part of HAZ.

Because of the high temperatures in the hot part of HAZ next to the weld, primary carbides disolved fast in the austenite matrix which is enriched with chromium and carbon to the point of steel composition whose melting point is below the actual temperature in that part of HAZ. The occurance of the melt speeds up the melting process so the level of the melt increases. Normally this state does not last that long where the initiator of this occurance, primary carbide, would melt completely. In the cases studied the melt solidificated in the form of ledeburite eutectic (secondary) and it forms rougher spots with rougher constituents such as the elements of a net of the primary eutectic in the weld. That forces a question of how important the influence of the occurance has on the mechanical stability of the surface deposit by welding.

Because of the specific chemical and microstructural composition of ledeburite tool steel there comes to phase transformations by surfacing in the hot part of HAZ, not only in the solid state but there are also transformations going from solid state – melt – solid state. Secondary eutectic is result of these transformations.

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Note: The responsible translator for English language is Tanja Goršič, University of Ljubljana, Slovenia.