Effect of heat treatment on the microstructure, hardness and abrasive wear resistance of high chromium hardfacing

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Abstract

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The effect of destabilization heat treatment on the microstructure, hardness, fracture toughness and abrasive wear resistance of high chromium hardfacing was investigated. The results from the study shows that the hardness, fracture toughness and abrasive wear resistance are influenced by temperature of destabilization heat treatment and air and furnace cooling conditions, respectively. Destabilization treatment of materials by furnace cooling caused higher secondary carbides in the dendritic austenite whilst by air cooling it showed smaller particles of secondary carbide. Also, it was found that destabilization temperature at 1,000°C improves hardness compared with hardfacing after weld depositing. The study, however, indicated that Palmqvist fracture toughness method is a useful technique for measuring the fracture toughness of high chromium hardfacing compared to Vicker's hardness method.

Keywords: destabilized austenite; carbide; dry rubber wheel test; factorial regression; GMAW (Gas Metal Arc Welding); toughness

High chromium hardfacing was widely used in mining, minerals industry and agriculture because of their excellent abrasion resistance (Chotěborský et al. 2008; Horvat et al. 2008; Brožek et al. 2010). Microstructure of high chromium hardfacing after weld depositing consists of hypoeutectic, eutectic or hypereutectic microstructure (Atamert, Bhadeshia 1990). Previous work (Chotěborský et al. 2011) showed that increasing the volume fraction of eutectic carbides improves the abrasion resistance. Other possibility for increasing the abrasion resistance is the use of carbide forming element such as vanadium, tungsten, molybdenum or niobium into hardfacing metals (Berns 2003; Berns et al. 2011). Especially niobium is an alloy which is currently used for creating microstructure of hardfacing with very hard niobium carbide (NbC) (Xiaohui et al. 2008). These hardfacing materials usually contain molybdenum, which can withstand high temperatures (Wang et al. 2008). Other works (Arikan et al. 2001; Bedolla-Jacuinde et al. 2005; Badisch et al. 2008) show possibility of titanium for the development of TiC in microstructure hardfacing. These studies showed that titanium carbide (TiC) formation into hardfacing increases abrasive resistance more than hardfacing containing NbC.

Some studies (Radulovic et al. 1994; Badisch et al. 2008) also highlight that increasing of volume fraction of eutectic carbides influenced toughness

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negatively. One of the ways for developing relatively toughness hardfacing is the use of fine grains of eutectic colonies. Currently, hardfacing with complex alloys element is used for developing eutectics microstructure in the matrix of hardfacing with hard particles of niobium (Berns, Fischer 1997; Correa et al. 2007; Xiaohui et al. 2008) or titanium carbides (Arikan et al. 2001; Xiaojun et al. 2007; Wang et al. 2008). However, other ways for increasing toughness is heat treatment of hardfacing. Some studies (Gahr, Doane 1980; Zhang et al. 2001) showed that destabilization of heat treatment of low carbon white cast iron improves toughness. Also the presence of austenite in the matrix can positively contribute to abrasion resistance, due to work hardening and stress-induced martensitic transformation, which provides good support to the carbide (Kazemipour et al. 2010). Further research (Gahr, Doane 1980; Turenne et al. 1989; Radulovic et al. 1994) shows that the presence of 25 to 30% retained austenite in the matrix results in the best abrasion resistance. But it is known that (Sare, Arnold 1995) 30–50% retained austenite is the optimum.

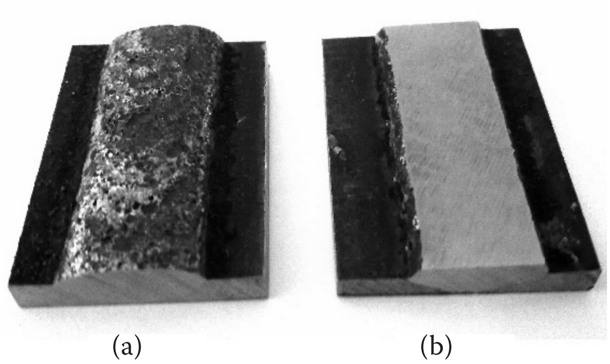
The aim of the present study is to determine the effect of heat treatment on the microstructure, hardness and abrasive wear resistance of hardfacing alloy.

MATERIAL AND METHODS

The commercial hardfacing electrode was applied onto S235JR steel plates (ArcelorMittal Ostrava a.s., Ostrava, Czech Republic) 40 × 20 × 300 mm. The nominal chemical composition of S235JR steel and electrode (SK43-O) is shown in Tables 1 and 2, respectively. The deposition was carried out in flat position using ESAB Mini 2A welding machine (ESAB Vamberk s.r.o., Vamberk, Czech Republic); the welding process parameters with constant welding speed was 20 cm/min, arc current of 300 A and welding voltage of 30 V were applied. Samples after weld depositing and testing are presented in Fig. 1.

Table 1. Chemical composition of the base material (wt. %)

C	Mn	S	P	Fe
0.074	0.33	0.006	0.002 5	rest



(a) (b)

Fig. 1. Sample after weld deposit and cuts from base material (a) and sample for abrasive wear resistance test (b)

The hardness of the hardfacing deposits was measured by the Vickers method (HV30) using a load of 294 N and HV30 method with a 294 N load was repeated eleven times per sample. Optical microscopy (Zeiss Jenavert; VEB Carl Zeiss Jena GmbH, Jena, Germany) was used to analyse the microstructure of the specimens. The surface was grinded, polished and etched with picric acid (2% solution) before analysing. The hardness of the matrix phases was measured by the Vickers method for microhardness using a load of 0.098 N (HV0.01) also repeated eleven times per sample. The Palmqvist fracture toughness was measured by indentation method (Fig. 2). The polished surfaces were intended by Vickers indenter at loads 294 N or 981 N. Existence of crack was measured by optical microscopy (Meacham et al. 2006; Duszová et al. 2011). The Palmqvist toughness W_G (N/mm) was determined as:

$$W_G = \frac{F}{T} \quad (1)$$

where:
F – load (N)
T – total crack length (mm)

The Palmqvist fracture toughness W_K (N/mm) was determined as:

$$W_K = 0.0028 \times \sqrt{HV} \times \sqrt{W_G} \quad (2)$$

where:
HV – hardness (N/mm^2)

Table 2. Chemical composition of the hardfacing electrode (wt.%)

C	Si	Mn	Cr	Mo	Nb	V	W
4.50	0.50	0.70	17.50	0.90	5.00	1.00	1.00

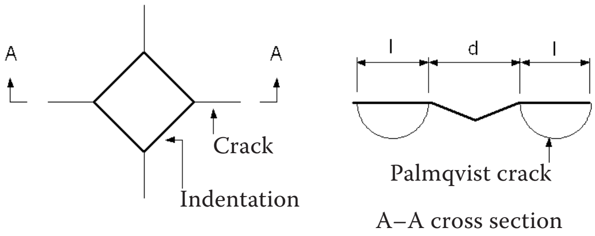


Fig. 2. The planar and cross sectional views of the Palmqvist crack model

Abrasive wear test (five times per samples) was carried out in a dry rubber wheel machine (Fig. 3) using sand particle 0.2–0.3 mm (Fig. 4). The load on specimen was 30 N, wear distance was 250 m. Diameter of rubber wheel was 130 mm and width was 10 mm. Before testing, all specimens were cleaned in ultrasonic bath and rinsed with warm air. The abrasive wear resistance was determined from the volume loss results, which was measured with 0.1 mg resolution.

The volume loss V (m^3) was determined by mass loss using Eq. (3).

$$V = \frac{m}{\rho} \quad (3)$$

where:
m – mass loss of material (kg)
ρ – density (kg/m^3) of the tested material

Density of hardfacing layer was 7,580 ± 21 kg/m^3; it was determined according to hydrostatic method (Kittel 1985).

RESULTS AND DISCUSSION

High chromium hardfacing consists of austenitic dendrites, an interdendritic eutectic carbides and austenite and primary carbide NbC (Fig. 5). After destabilization treatment by air cooling or furnace cooling, secondary carbide precipitation occurred in the dendritic austenite (Fig. 6). It can be seen that cooling rate after destabilization treatment influenced the size of secondary carbides which occurred in the dendritic austenite. The results show that lower cooling rate by furnace cooling leads to higher secondary carbides in the dendritic austenite (Fig. 7). Contrary, air cooling leads to smaller particles of secondary carbides in the dendritic austenite. After destabilization treatment and quenching by water, secondary carbide precipitation occurred in the dendritic austenite and the amount of transformed martensite.

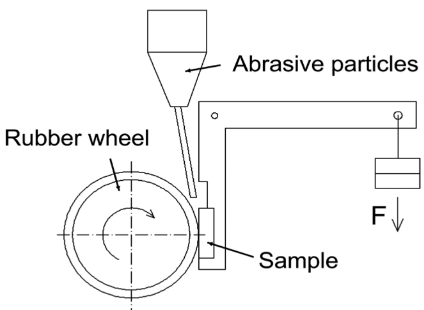


Fig. 3. Schema of abrasive wear tester

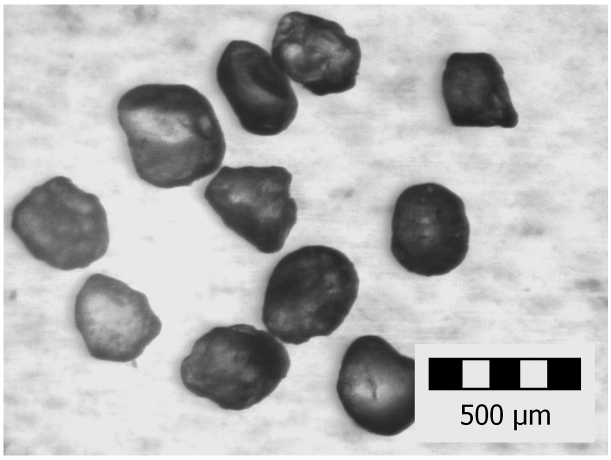


Fig. 4. Abrasive particles – sand

Table 3 shows the Vickers hardness of the hardfacing at different heat treatment conditions. It was found that destabilization temperature at 1,000°C and quenching in the water dramatically improved the hardness compared with hardfacing after weld depositing. Destabilization heat treatment does not significantly influence hardness of eutectic but significantly influences hardness of austenite (Table 4). Hardness of hardfacing after destabilization heat

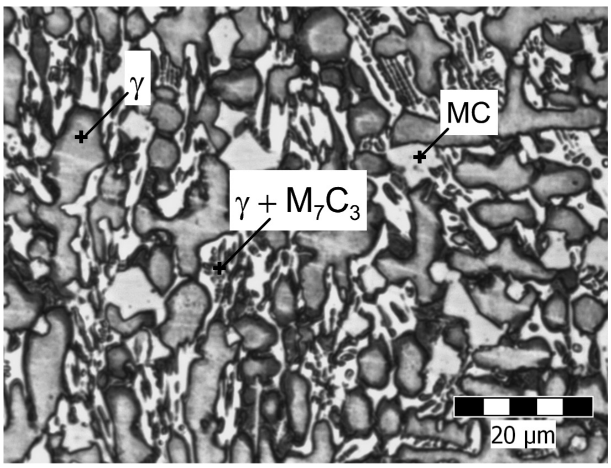


Fig. 5. Optical microstructure of hardfacing after weld depositing

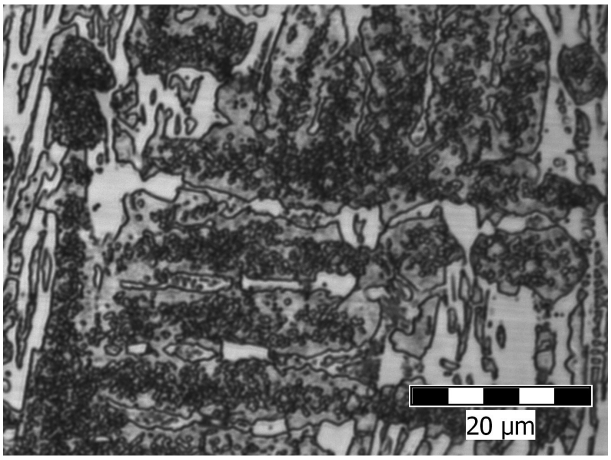


Fig. 6. Optical microstructure of hardfacing after destabilization at 1,000°C for 120 min by air cooling. Carbides are now clearly visible in the austenite

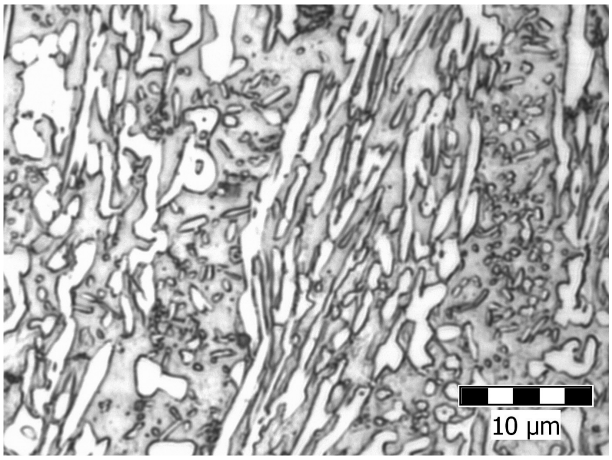


Fig. 7. Optical microstructure of hardfacing after destabilization at 1,000°C for 120 min by furnace cooling. Carbides are now clearly visible in the austenite

treatment and cooling by furnace was the lowest. This could be to due larger particles of secondary carbides present in the dendritic austenite. Also microhardness of dendritic austenite as a result of the transformation of austenite to martensite by loading is low. This effect might be due the change of carbon content in the dendritic austenite since carbon is involved in the formation of secondary carbides.

The Palmqvist toughness (Table 5, Fig. 8) shows that fracture toughness is influenced by phases in the microstructure of hardfacing. The destabilization heat treatment significantly influenced fracture toughness. From the results it is evident that cooling by air slows destabilization and using furnace improves fracture toughness. Also temperature of destabilization heat treatment and subsequent cooling in water influenced fracture toughness. Palmqvist fracture toughness methodology can be used for the evaluation of hardfacing toughness, but high fracture toughness of some hardfacing leads to

Table 3. Hardness and volume loss of the tested hardfacing and their heat treatment

	Hardness (HV30)	Standard deviation (HV30)	Volume loss $\times 10^3$/mm^3	Standard deviation $\times 10^3$/mm^3
Hardfacing	640	23	332	8.7
Quenching 900°C, 120 min, water	910	35	257	9.4
Quenching 1,000°C, 120 min, water	930	58	230	8.7
Quenching 1,100°C, 120 min, water	880	40	271	11.5
Destabilization 120 min, cooling in furnace 50°C/h	420	12	937	43.8
Destabilization 120 min, cooling in air	605	19	339	11.3

Table 4. Microhardness of phases of the tested hardfacing

	Hardness of eutectics (HV0.01)	Standard deviation (HV0.01)	Hardness of gama phase (HV0.01)	Standard deviation (HV0.01)
Hardfacing	1,050	55	750	75
Quenching 900°C, 120 min, water	1,035	62	885	67
Quenching 1,000°C, 120 min, water	1,020	65	930	96
Quenching 1,100°C, 120 min, water	1,030	48	920	65
Destabilization 120 min, cooling in furnace 50°C/h	980	45	690	58
Destabilization 120 min, cooling in air	1,020	50	785	70

Table 5. Palmqvist fracture toughness of the tested hardfacing

	Load 294 N	Load 981 N	W_K (N/mm)	Standard deviation (N/mm)
Hardfacing	yes	–	11.2	0.65
Quenching 900°C, 120 min, water	yes	–	7.21	0.47
Quenching 1,000°C, 120 min, water	yes	–	8.64	0.49
Quenching 1,100°C, 120 min, water	yes	–	6.95	0.62
Destabilization 120 min, cooling in furnace 50°C/h	no	no	N	N
Destabilization 120min, cooling in air	no	yes	16.2	0.75

Table 6. Effect of the factor on volume loss of hardfacing

Factor	Value of effect	*t* score	*p* - value
Hardness	–109	–88	0.007
Toughness	–34.5	–30.5	0.021
Hardness × toughness	–21.1	–23.4	0.027

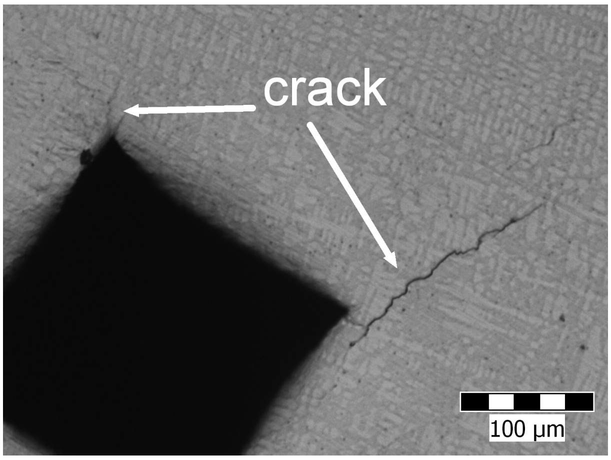


Fig. 8. A typical surface crack in the hardfacing after weld deposit, indented with 30 kg

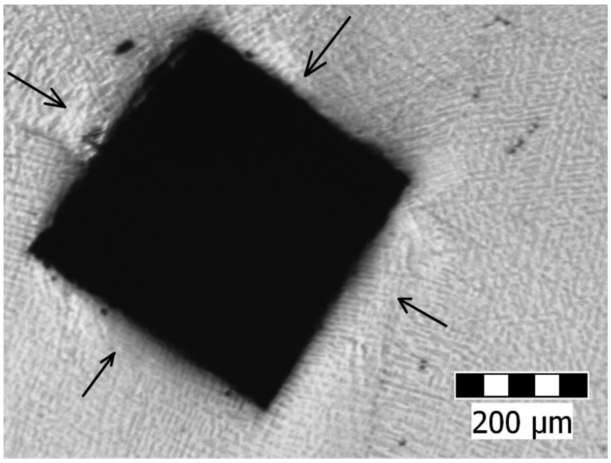


Fig. 9. Hardfacing after destabilization heat treatment and cooling in furnace 50°C/h indented with 100 kg load

higher loading than standard force for Vicker's hardness tester. For example sample which was destabilized and cooled by furnace had higher toughness than the required value for crack initiation. Loading at 100 kg caused deformed surface around indentation (Fig. 9), but without the initiation of crack.

Abrasive wear resistance represented by volume loss showed that wear resistance does not only depend on the hardness but it is also influenced by toughness. This claim is evidenced by factorial regression, whose results are shown in Table 6. Abrasive wear resistance of hardfacing after weld deposit and after destabilization heat treatment with cooling by air have similar volume losses but significantly different hardness and fracture toughness. Results show that higher fracture toughness improves wear resistance though hardness of hardfacing can be lower. But, higher rate of hardness decreased abrasive wear resistance. Also destabilization heat treatment and quenching in the water showed different wear resistance.

CONCLUSION

The study shows that the Palmqvist fracture toughness method is a valid technique for measuring the fracture toughness of high chromium hardfacing.

Also the abrasive wear resistance of high chromium hardfacing depends on hardness and fracture toughness after heat treatment. Destabilization heat treatment causes secondary carbides in the dendritic austenite. Hardness and fracture toughness are influenced by destabilization heat treatment. Again, the abrasive wear resistance depends on the hardness and the fracture toughness of high chromium hardfacing.

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