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The Effect of Low Temperature Austempering Process on Microstructure, Mechanical and Wear Properties of AISI 52100 Steel

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1- Introduction

AISI 52100 is a high carbon, low alloy steel that can achieve suitable ultimate strength, hardness and abrasion resistance. Low fracture toughness and destructive residual tensile stress are the main problems of this steel. A number of attempts such as formation of bainitic microstructure have been made to overcome this drawback. However, this steel is not quite amenable to austempering process, and it may typically take several days to reach the desired degree of transformation. Although the conventional bainitic structure may not be an attractive proposition for ball-bearing applications, formation of ultrafine-bainitic (super-bainitic) structure in this steel may prove superior in terms of mechanical properties including hardness, tensile strength and toughness as compared to those obtained in the usual hardened and tempered condition.

Although, a lot of studies have been conducted about the formation and characterization of bainitic structure in AISI 52100 steel [10,11], the exact effects of low temperature austempering treatment on the structure and mechanical properties of this steel has not been properly investigated. Therefore, this report attempts to determine the effect of low temperature austempering process on the structure and mechanical properties of AISI52100 steel.

2- Experimental

Cylindrical samples of 22 mm diameter and 5 mm thickness were cut from an ingot of AISI 52100 steel. The samples were austenitized at 1050 ºC for 60 min and then rapidly transferred to a salt bath furnace in the temperature range of 150-300 ºC. The structure of prepared samples was investigated using a field-emission scanning electron microscope. An X-ray diffractometer with Cu Ka radiation was also used to follow the structural changes of the specimens. Room temperature mechanical properties of produced specimens were also studied according to ASTM E8M-04 standard. The wear behavior of the prepared samples was examined using pin on disc test.

3- Results and Discussion

The mechanical properties of austempered samples at 150 ºC for different periods of time up to 288 h are presented in Table 1. According to this table, all austempered specimens at this austempering temperature have broken in the elastic region and the ductility of produced samples is close to zero. The SEM micrographs of austempered samples at this temperature for 288 h are presented in Fig. 1. According to this figure, the microstructure of austempered sample at 150 ºC for 288 h, is composed of bainitic ferrite (α_{BF}) and the retained austenite with two morphologies: as micrometer-blocks (γ_{MB}, >1000 nm) between the sheaves of bainitic ferrite plates and as nano films (γ_{NF}, <100 nm) between the subunits of bainite. This result confirms that the carbon-rich retained austenite is stable at 150 ºC and its transformation to bainitic ferrite structure is a time-consuming process. In fact, the carbon-rich retained austenite can be turned into high-carbon un-tempered martensite, during the deformation process. The percentage of retained austenite in these samples is so high that the formation of brittle un-tempered martensite during deformation is the main reason of low ductility of austempered samples at this temperature.

Table 1 Mechanical properties of austempered samples at 150ºC for different time periods

	Time (h)					
	0	24	48	96	192	288
Hardness (Hv)	570	540	532	505	495	480
Strength (Mpa)	–	–	–	717	1358	1384
Elongation (%)	–	–	–	0	0	0

The mechanical properties of austempered samples at 200 ºC for different times are presented in Table 2. According to this table, the fracture mechanism in these specimens is also brittle, and the amount of ductility is about zero. In this regards, the SEM micrograph of austempered specimen at 200 ºC for 192 h are shown in Fig. 2. As seen, the microstructure of this sample is similar to the micrograph of austempered samples at 150 ºC and consists of bainitic ferrite (α_{BF}) and retained austenite. Same as above, the bainitic transformation has not been completed at this austempering condition (until 192 h) and the low ductility of produced samples can be related to the presence of retained austenite in the microstructure.

The mechanical properties of austempered samples at 250 ºC for different times are presented in Table 3. As seen, by increasing the annealing time at this austempering temperature, the mode of fracture has changed from brittle to ductile and the ductility of the produced specimens increased to about 7 %. The SEM cross-sectional micrograph of austempered sample at 250 ºC for 96 h is shown in Fig. 3. According to this figure, the bainitic transformation is complete at this austempering condition and the microstructure of this sample only consists of bainitic-ferrite (α_{BF}) and nano films (γ_{NF}) of retained austenite. In fact, there is no evidence of micrometer-block austenite phase in these microstructures. It is important to note that, decreasing the

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amount of retained austenite from the microstructures is the main reason of increasing the ductility of these samples.

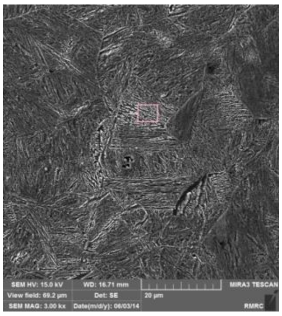

Fig. 1 SEM micrograph of austempered samples at 150°C for 288 h

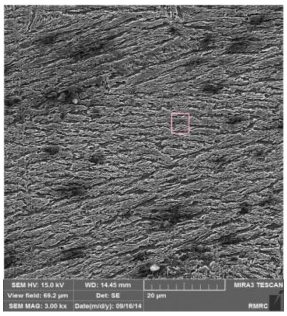

Fig. 2 SEM micrograph of austempered samples at 200°C for 196 h

Table 2 Mechanical properties of austempered samples at 200°C for different time periods

	Time (h)					
	0	**24**	**48**	**96**	**144**	**192**
Hardness (Hv)	570	530	505	483	462	450
Strength (Mpa)	–	–	564	868	1153	1171
Elongation (%)	–	–	0	0	0	0

Same as above, the mechanical properties of austempered samples at 300 °C for different periods of time are presented in Table 4. According to this table, the strength and ductility of austempered samples at 300 °C (1808 MPa, 3 %) is lower than prepared samples at 250 °C (2000 MPa, 7 %). In this regard, the cross-sectional micrograph of austempered sample at 300 °C for 48 h is shown in Fig. 4. According to this figure, the structure of austempered samples at 300 °C only consists of bainitic-ferrite phase, and there is no evidence of micrometer-block retained-austenite in the microstructure. The shape of bainitic-ferrite phase in these specimens is different from other austempering conditions and the transformation products do not have a layered structure. Moreover, the size of the formed bainitic-ferrite after austempering at 300 °C is greater than other austempering conditions, which can be related to the lower nucleation rate and higher growth rate of ferrite at higher temperatures. By attention to these results, the reduced strength and ductility observed in the product samples in this condition can be related to changes in the shape and size of the formed phases.

Table 3 Mechanical properties of austempered samples at 250°C for different time periods

	Time (h)					
	0	**1**	**24**	**48**	**72**	**96**
Hardness (Hv)	570	520	490	445	425	420
Strength (Mpa)	–	576	1588	2006	-	2024
Elongation (%)	–	–	0	4.2	–	7.25

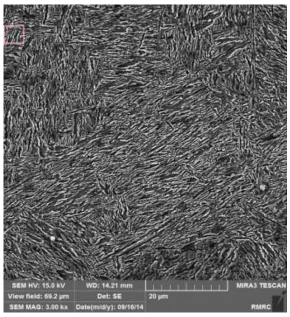

Fig. 3 SEM micrograph of austempered samples at 250°C for 96 h

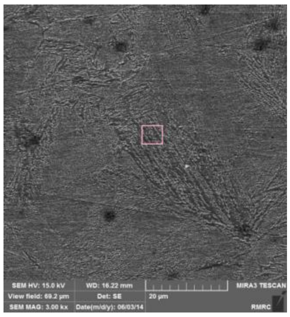

Fig. 4 SEM micrograph of austempered samples at 300°C for 48 h

Table 4 Mechanical properties of austempered samples at 300°C for different time periods

	Time (h)			
	0	**1**	**24**	**48**
Hardness (Hv)	570	472	423	420
Strength (Mpa)	–	-	1756	1739
Elongation (%)	–	–	6.35	5

4- Conclusions

The microstructure of this steel after austempering process consists of ultrafine bainitic-ferrite plates and retained austenite with two morphologies of micrometer-block and fine film. At austempering temperature up to 250 °C, the micrometer-blocky morphology of austenite was vanished completely and the strength and ductility was increased to about 2000MPa and 7 %, respectively. By increasing the austempering temperature, the strength and ductility were reduced (to about 1808MPa and 3%) simultaneously.