ANALYSIS OF THE MICROSTRUCTURE AND WEAR RESISTANCE 35CRSIMN5-5-4 STEEL AFTER QUENCHING AND PARTITIONING

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Abstract

In recent years, the intensive research work have been carried out on the development of heat treatment which allowed obtaining a carbide-free microstructures with retained austenite. These include the quenching with isothermal annealing (austempering) leading to obtain a nanocrystalline bainite [1, 2] and Quenching&Partitioning (Q&P) [3] leading to obtain a microstructure composed of carbon-depleted martensitic matrix and carbon-enriched retained austenite. These processes are suitable for steels containing alloying additions of Silicon and Aluminum, that suppress formation of iron carbides [3]. In the case of Q&P process the quenching is performed at temperature (T_Q) below M_S in order to obtain an incomplete martensitic transformation. The stability of retained austenite is obtained by carbon partitioning from martensite to thin interlath films of untransformed austenite. Carbon partitioning process occurs during isothermal holding at partitioning temperature (T_P) directly after cooling to the quenching temperature (T_Q). The increased volume fraction of retained austenite may improve toughness of steel [4, 5]. Moreover such steels may exhibit the TRIP effect which promotes the ductility [6, 7].Our preliminary studies showed that metastable retained austenite in microstructure may also improve wear resistance [8]. In this study an attempt to obtain microstructure composed of martensite and retained austenite in 35SrSiMn5-5-4 steel by means of Q&P process was undertaken. The parameters of Quenching and Partitioning were designed to receive about 22% of stable austenite in 35SrSiMn5-5-4 steel at room temperature. It was shown [8], that such amount of retained austenite should improve wear resistance in comparison to the same steel subjected to conventional heat treatment consisting on quenching followed by tempering.

Keywords: steel, quenching & partitioning, martensite/austenite mixture, wear resistance

1. EXPERIMENTAL MATERIAL AND PROCEDURE

Chemical composition of 35CrSiMn5-5-4 steel treated by Quenching&Partitioning process is shown in Table 1

Table 1 Chemical composition of the 35CrSiMn5-5-4 steel

	C	Cr	Mn	Si	Ni	Cu	Al	Mo	W	Fe
Wt%	0.35	1.31	0.95	1.3	0.14	0.15	0.04	0.018	<0.03	reszta

The Ms and Mf temperature of 35CrSiMn5-5-4 steel were determined by use of dilatometric tests. The tests have been carried out with the use of a quenching dilatometer Bahr 805L. The samples used in the dilatometer had cylindrical shape: ø=3mm, h=10mm. The Ms and Mf temperature are respectively 345°C and 140°C. Both stages of the Q&P process were conducted below Ms temperature. The samples were austenitized at 900°C for 30 min, subsequently quenched into a oil bath at 235°C for 10 s then up-quenched into another oil bath at 260°C for 15min, and finally water cooled to room temperature. The quenching temperature T_Q=235˚C which allowed obtaining about 22% retained austenite in microstructure was selected on the basis of dilatometric tests and using the Koistinen-Marburger relationship [9]:

$$F_{aust.} = e^{((-1.1\times10^{-2})\times(M_s - T_Q))} \qquad (1)$$

where $F_{aust.}$ is the fraction of austenite that wasn't transformed to martensite upon quenching to a temperature T_Q [˚C] below the M_s temperature [˚C]. The holding time at T_Q was intended to provide temperature equalization in the cross-section of the treated samples. During annealing at 260°C for 15min the carbon partitioning occurred from as-quenched martensite to retained austenite. The partitioning temperature T_P=260˚C was selected using following relationship [10]:

$$t_p = \frac{\bar{x}_a^2}{6\times D_a} + \frac{\bar{x}_m^2}{6\times D_m} \qquad (2)$$

where $\bar{x}_a$, $\bar{x}_m$ – is the average diffusion distance in austenite and martensite, respectively

D_a, D_m – is the diffusion coefficient of carbon in austenite and martensite, respectively

Conventional treatment – martensitic quenching and low-temperature tempering has been carried out in order to compare properties of steel containing tempered martensite with steel containing a microstructure obtained by Q&P process. The samples of 35CrSiMn5-5-4 steel were austenitized at 900°C for 30 min, subsequently quenched in oil bath at room temperature then tempered in air at 230°C for 1h. The hardening oil for structural steels has been used as a cooling medium.

Samples treated by Q&P process have been subjected to microstructural observations using (TEM) JEOL 1200 transmission electron microscope working at a voltage of 120kV. The phases present in the microstructure were identified by electron diffraction patterns analysis. In order to determine the phases composition and particularly the austenite volume fraction the stereological analysis has been performed. Relative volume of phase components was calculated assuming that the amount of particular phase in microstructure is equivalent to its share on the image. Phase fractions V_V were calculated using following relationship [11]:

$$V_V = \frac{\Sigma c_{ik}}{nl} \qquad (3)$$

where c_{ik} is the sum of the length of sections laying within particular phase on the total length of the secants.

Hardness were measured using Vickers diamond testing machine with an applied load of 2kG. Wear tests were conducted on a T-01 tester with „Pin-on-Disc" configuration according to ASTM G99-90. Tribological conditions were as follow: counter specimen was ball made of Al_2O_3 - ϕ=10 mm, applied load - 9,81 N, linear velocity - 0,1m/s, sliding friction - 1000m. The wear measurements were reported as the volume loss in cubic millimetres for the disc, assuming that there was no significant ball wear. For calculating a disc volume loss the following equation has been used:

$$V = \frac{\pi\times r\times t^3}{6\times R} \qquad (4)$$

where V is the volume loss [mm^3], r – wear track radius [mm], t – track width [mm], R – ball radius [mm]

Track width has been measured using Nicon Eclipse MA200 light microscope.

2. EXPERIMENT AND DISCUSSION

The microstructure obtained as a result of Q&P process consisted on martensitic matrix and carbon-enriched retained austenite. Fig. 1 displays bright field micrographs of submicron martensite laths, films of inter-lath retained austenite and block austenite in 35CrSiMn5-5-4 steel quenched at 235˚C and partitioned at 260˚C.

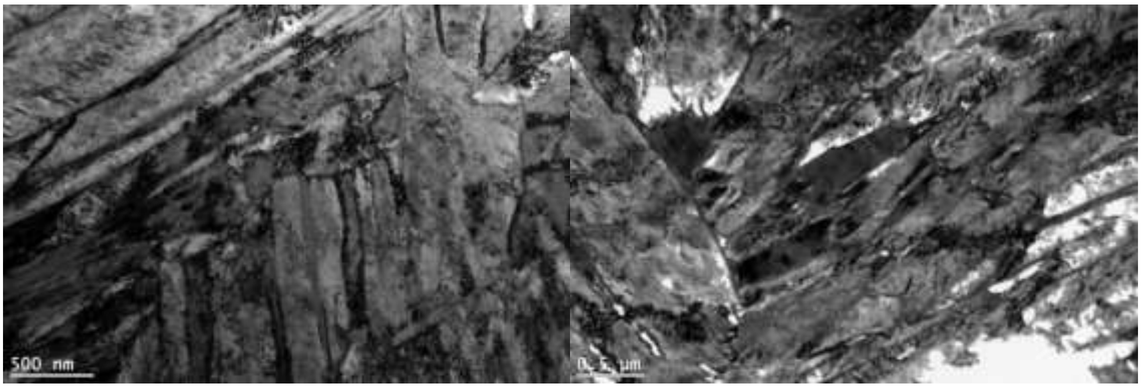

Fig. 1 Microstructure of 35CrSiMn5-5-4 steel after quenching at 235°C_and partitioning at 260°C-for 15min – TEM bright field

The relative volume of retained austenite estimated on the basis of micrographs was equal to 20% ± 3,5 %. The high volume fraction of austenite in steel lead to the TRIP effect, which may result in the increase of both the fracture toughness, strength and elongation during a deformation [12,13]. The iron carbides were observed in the carbon-depleted martensite laths. The competition of carbon partitioning with carbide precipitation could reduce the amount of stable austenite fraction.

Steel samples treated by Q&P had hardness value in the range of 450HV2 the same steel after quenching and tempering in air at 230°C had a hardness of about 555HV2. The results of wear resistance carried out by "Pin-on-Disc" is shown in Fig. 2.

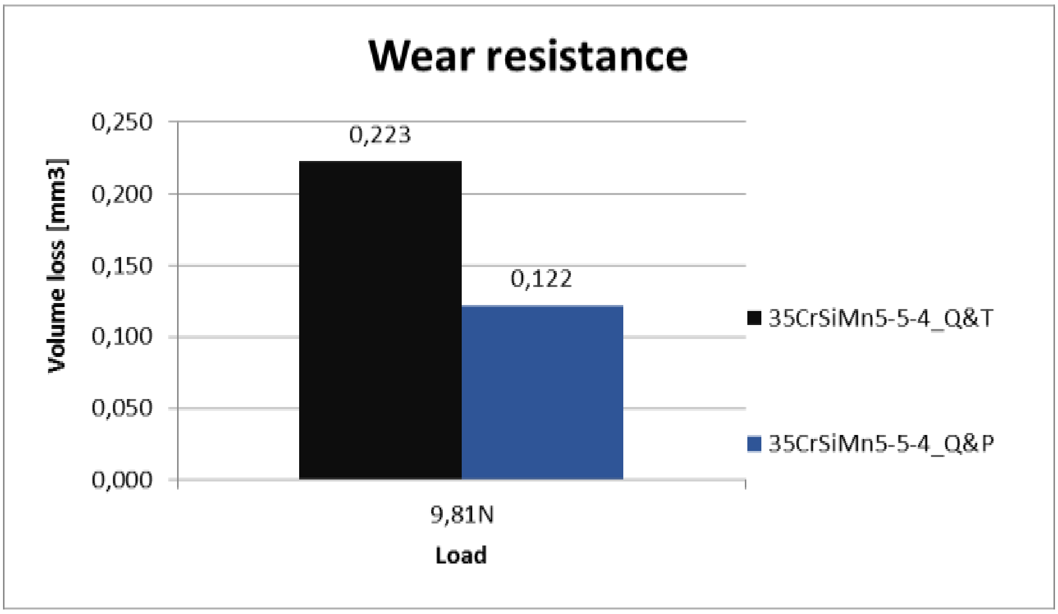

Fig. 2 Volume loss of the samples after sliding friction

The wear tests indicate, that microstructure obtained after Q&P process has better wear resistance in comparison to steel with tempered martensite obtained by conventional heat treatment, in spite of lower hardness of about 100 HV2 units. This can be related to high volume fraction of retained austenite (20%) in the microstructure, which under sliding friction may transformed into martensite leading to TRIP effect as it was shown in papers: [8, 14 and 15]. This phenomenon may increase the hardness at the interface, which can improve wear resistance compared to conventionally treated samples [15].

3. CONCLUSION

Quenching&partitioning heat treatment allowed us to obtain in 35CrSiMn5-5-4 steel a microstructure consisting of carbon-depleted martensite and carbon-enriched retained austenite. This microstructure has better wear resistance compared to microstructure obtained as a results of conventional heat treatment, in spite of lower hardness.

The obtained results indicate that 35CrSiMn5-5-4 steel samples after quenching and tempering with higher hardness exhibit lower wear resistance, than steel samples treated by Q&P. This effect can result from higher content of retained austenite after Q&P in comparison to microstructure obtained by hardening and low-temperature tempering. The retained austenite may transformed into martensite under the dry sliding friction [10]. This transformation increases hardness at the interface, which improves abrasion resistance with respect to that of the conventionally treated specimens.

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