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## Lower bainite phase formed in austempering

1 Introduction Low-temperature bainite has fine microstructures and finally tensile strength. Studies on steels containing approximately 0.8 wt% C have shown that the mechanical properties of the final tensile strength of 2500 MPa, hardness 600-670 HV and toughness of more than 30-40 MPa m<sup>1/2</sup> can be achieved by the formation of a low temperature bainite microstructure. These bainites, consisting of slabs of bainite ferrite and films of retained austenite, benefited from its ferrite plate with isothermal transformation at 200 °C. In addition, when adding ~2 wt% Si can be retarded the precipitation of cementite from austenite, leading to a bainite microstructure without carbides [1, 2, 3]. To obtain the ideal microstructure, different heat treatment processes were used for different steels. It has been reported that a low-temperature microstructure of bainite can be obtained for 60Si2CrVA steel after isothermal treatment of bainite transformation at 235 °C and the tensile strength of steel can be achieved as ~1980 MPa [4]. The low temperature bainite was obtained in 40SiMnNiCr steel, which was subject to the Q&P process (off at 180 °C by 60 s and processed at 300 °C for 120 s), resulting in a final tensile strength of ~2000 MPa [5]. At 0.2C-1.5Mn-1.5Si-0.6Cr-0.05Nb (wt%) a new treatment, which is shut-off steel, was used and resulted in approximately 10 % vol. of retained austenite in steel, compared to approximately zero percent of retained austenite-martensite transformation after traditional treating-tempered treatment, which may affect the stress-stress property relative to the potential strain-induced austenite-martensite transformation [6]. The low temperature nanobainitic structure was obtained for steel with 0.85 wt% C, with a two-step, high tensile strength of 1955 MPa with a total 7 % weighting [7]. They investigated the effect of a relatively high isothermal temperature (400 °C) on the microstructure of low-carbon, high-Al low-Si steel, and the bainite structure produced a high product of tensile strength and exite as 17, 695 MPa% [8]. In-situ observation was carried out to analyse the bainite transformation of low-carbon steel under tensile loading [9]. However, the impact of isothermal temperature and carbon content on bainitic transformation should be further discussed. Bainite transformations and the impact on mechanical properties have been widely studied for steels with a relatively low carbon content. However, studies on low-temperature bainist steels with more than 1 wt% C are rarely reported. Studies have been carried out on the development of 1.05 wt% carbon-based ultra-high strength steel structures. Mechanical tests were carried out to reveal the relationship between the microstructure and the mechanical properties of high-carbon steel. 2 Experimental procedures steel is high-carbon steel with a composition (wt%) Fe-1.1C-1.5Si-1.1Mn-1.4Cr-0.5Mo-0.6Al-0.6Co, as high carbon would prolong the period of beginning of the bainite transformation, co and al were added to accelerate the introduction of the bainite transformation [2]. The phased transformation software MUCG 83 [10] analysed the phase transformation of the experimental steel in question. Figure 1a shows the calculated TTT diagram to start the determination of the bainitic transformation. DTA was employed to measure ac1, Accm steel with a heating rate of 10 °C/min from ambient temperature to 1400 °C as shown in Fig. 1b. It can be found that ac1 and Accm experimental steel are 810 and 1020 °C respectively. b the measured differential thermal analysis differential diagram (DTA) for determining the temperature of the phase transformationS the microstructure was carried out by optical microscopy (OM) and jem-2100 portable electron microscopy (TEM) operating at 200 kV. The phase composition in the samples was analysed by the D/max-2500PC X-ray difactometer (XRD) with CuK $\alpha$  radiation. Rockwell hardness tests were performed to measure integral hardness, and for each sample the result is the average value of five measured values at different positions. Various heat treatment processes have been employed, including traditional austempering processes and the self-developed A-P-T process. For traditional austempering, the samples were insoud at 1100 °C, held for 30 mins and then filed in a 250, 280 and 300 °C salt bath with a different holding time. For the A-P-T procedure, the samples taken were switched off for 8 h in a 300 °C salt bath and then cooling the water to room temperature, then, svi samples su are warmed to 300 °C for 2 h for elements of diffusion (called process partition) i finally cooled at room temperature air. 3 Results i discussion i discussion of the structure of extra high-carbon cell huleading austemperingu under various conditions given su on Fig. 2, from which the typical morphology of the needle is shown in the dolka bainiteu. This can be seen from Fig. 2a that the main stage of the sample martensit i that only a small selection of bainite is entiated after isothermal transformation at 300 °C for 4 h. From fig. 2b, the light that su sewing bainita became longer and crowded i da su buy even the original austenito nugget tub, the weather of holding was extended to 10 h to 300 °C. We can defer, that isothermal time can influence the precipitation behaviour of carbide from austenitis, and the bainita transformation is approximately complete, as the retention time was extended to 10 h at 300 °C. in samples subjected to austempering at 280 °C (Fig. 2c, d) and 250 °C (Figure 2e, f), but the transformation rates at a lower temperature were much slower because it is controlled by the rate of carbon diffusion at the interface  $\alpha/\gamma$ , which is influenced by the temperature. Compared to the morphology of completely modified bainite under different temperatures, the bainite needles have become more fine and denser, when the holding temperature has decreased from 300 to 250 °C. The possible reason is that carbon diffusion becomes more difficult when the temperature is lower, which limits the coarsening bainite.SI. 2Figure Option Fig. 2 Optical images of high carbon alloy steel after austempered at different temperatures for different times: 300 °C, 4 h; b 300 °C, 10 h; c 280 °C, 10 h; d 280 °C, 20 h; E 250 °C, 20 h; f 250 °C, 38 hFigure 3 shows the result of X-ray samples of samples treated with different procedures, indicating that there is a bainitic ferrite ( $\alpha$ ) and retained austenite ( $\gamma$ ) in the treated samples. Calibrated diffraction peaks prove that cementite does not appear during the cooling process. The volume of communal austenite, in  $\gamma$ , can be calculated using the equation in ref. [12] The results showed that the austenite content decreased by reducing the temperature of the austempering. The values were approximately 61.0% vol for the sample of 300 °C/10 h, approximately 55.0 vol for the sample 280 °C/20 h and approximately 54.7 vol% for the 250 °C/38 h sample. The results are in good agreement with the OM observations referred to in Fig. 2. As the holding time increased further and the holding temperature decreased further, the volume of the austenite retained was reduced. The austenite content in the sample of 280 °C/20 h was almost the same as in the sample of 280 °C/38 h, which was different from the reported results [1,2, 3]. Carbide wasn't detected. Therefore jer 1.5% You could inhibit formation, a time i carbon enriched retained austenit i bainite.SI. 3Figure Option Fig. 3 XRD samples of high-carbon cell cheeks austempered at different temperatures for other weather: 300 °C, 10 h; b 280 °C, 20 h; c 250 °C, 38 hFigure 4 shows tem microstructures and the corresponding selected electron diffraction area (SAED) sample of bainite ferrite plates and retained austenitis. Carbides have not been detected, so bainites can be called bainites without carbide. Microstructure patterns in the current part are different from the results of experiments in the ref. [1] May be due to a high carbon content (&gt; 1 wt%). The thickness of the bainite ferris plates are approximately 150 nm in the 300 °C treated sample, approximately 100 nm in the 280 °C treated sample and approximately 60 nm in the 250 °C treated sample, or finer than the sample reported in the ref. [4] for steel 60Si2CrVA. Due to the fine bainite ferritic plate and the low content of retained austenite, the tensile strength of the samples subjected to 250 °C outstempering for 38 h is the highest, while is the lowest as listed in table 1.SI. 4Figure Option Fig. 4 THE PICTURE OF HIGH CARBON STEEL, at 300 °C for 10 h a, 280 °C for 20 h b, 250 °C for 38 h c, i corresponding SAEDs sample d bainite ferrit flat If i retained austenitTable 1Table 1 Table 1 Mechanical properties of high-carbon all cellular cell hinged under austempered treatmentTreatmentield strength (MPa)Tensile strength (MPa)Exhidle (%)Hardness (HRC)3 00 °C for 10 h1142.91467.74.647.2280 °C for 20 h1470.51623.75.149.5250 °C for 38 h1677.02003.13.253.9 Table 1 Mechanical properties of high carbon alloy steel under various austempered treatments from Table 1, can be seen from 47.2 to 53.9 HRC with a range of austempering temperatures. High hardness is due to carbon reinforcement and the solubility of carbon in bainite ferrite is higher than with equilibration ferrites [12]. Two factors influenced the change in hardness with the temperature of the austempering treated samples: lower austenite content (soft phase) and thinner ferritic plates at low austempering temperature. When the temperature of the austempering was relatively low (250 and 280 °C), the retained austenite content did not change significantly and the thickness of the ferris plates played a major role in increasing the hardness. The highest tensile strength is around 2003 MPa for samples redesigned at 250 °C.Figure 5 indicates a double-sided microstructure of bainite-like needles and bamboo leaves of martensite. From Fig. 5a, it can be seen that a little bainita has been transformed at a shorter austempering (4 h) and a large martensit is produced through whole previously austenitis grains similar to microstructures obtained by the conventional Q-P-T process. However, with the increase in austempering time, a needle-like phase of the bainita and austenito grains were cut to smaller sizes and therefore cleaned out the size of martensite, which is constructive during cooling. As shown in Figure 5b, c.SI. 5Figure Option Fig. 5 Optical images of austempering-partitioning-temperament: austempered at 300 °C for 4 h and partitioned at 300 °C for 2 h; b austempered at 300 °C for 6 h and broken down at 300 °C for 2 h; c austempered at 300 °C for 8 h and partitioned at 300 °C for 2 hFigure 6 shows the duplex microstructure with nanostructured bainite and twin martensite after the A-P-T process. It can be seen that the secondary bainite appeared when the samples re-med at 300 °C (partition). The thickness of secondary bainite ferrit plates produced during processing is much less than the thickness of the primary bainite, which occurs during the process 300 °C austemperinga (top left), which can cause greater ductile and zlavost.SI. 6Figure Option Fig. 6 TEM picture of high-carbon ness after austempered at 300 °C for 8 h h area at 300 °C for 2 h a i corresponding SAED sample bMechanical tests performed for 300 °C for 8 h)-processing (300 °C for 2 h)-caleor, and the strength of the yield of 1112 MPa, tensile strength of 1533 MPa, 7.4% and hardness of 48.6 HRC was obtained. Compared to the results in Table 1, it can be concluded that the A-P-T treatment has increased steel ducticity with some reduction in strength. The mechanical property expressed as a product of tensile strength and complete dissuad has been significantly improved by the treatment process A-P-T. 4 Conclusions The thickness of low temperature bainitic ferrite plates in high-carbon steel with 1 wt% Cr reduced by a reduction in the temperature of austempering, from 150 nm to 300 °C to 60 nm at 250 °C, a film retained austenite content is i snio, from 61.0 vol% at 300 °C to 54.7% vol at 250 °C.Tensile strength and hardness have increased with a reduction in temperature austemperinga. The maximum tensile strength and hardness values were 2003 MPa and 53.9 HRC for a sample which, at 38 h at a temperature of 250 °C, was significantly improved compared to that which was subject to traditional austempering treatment. Treatment.

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