Effect of gas quenching rate on microstructure and hardness of SAE 1078 steel during austempering treatment

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Abstract

The patenting process is required to obtain the proper ductility and toughness of high carbon steel for subsequent cold forming by wire drawing or rolling. It is mainly used with lead media for patening treatment because the excellent heat transfer properties of lead achieve uniform temperature distribution. Replacing this process with technology that eliminates the use of hazardous lead presents challenges. In this study, our goal is to investigate the relationship between microstructure changes and mechanical properties according to isothermal temperatures and cooling rates using garnet powder as an alternative to lead media. After the austenizing treatment, the microstructure, hardness and friction properties of patented specimens at three isothermal temperatures (460, 560, 660 °C) and three compressed air flow rates (10, 50, 100 l/min) were analyzed to examine the relationship between mechanical properties according to lamellar spacing in pearlite. As the isothermal temperature decreases or the air flow rate increases, not only the lamellar spacing of perlite decreases, but also the banite structure is formed, which improves the hardness and wear characteristics.

Keywords: high-carbon steel, patenting, hardness, fine pearlite, wear resistance

1. Introduction

High-carbon steel plates with a carbon content in the range of 0.6–1.4 wt.% are hard and are used for cutting tools that require excellent hardness and high yield point by quenching effect [1]. It is also used for steel cord, a tire reinforcing material with excellent fatigue characteristics as well as strength, and automobile transmission parts [2-3]. The patenting process used to increase sufficient ductility and toughness mainly uses a Pb medium, which has a high heat transfer coefficient and high temperature uniformity, but is harmful to the human body of production workers and is not environmentally friendly because it generates fume and waste gas [4-5]. In addition, energy efficiency is poor due to large radiative heat loss, and lead supplementation and product post-processing are required. In particular, when products that have been treated with lead are exported, the post-processing process is complicated because advanced countries regulate the content of harmful substances. On the other hand, the fluidized bed heat treatment process is an eco-friendly process that not only maintains a uniform temperature depending on the location in the furnace because gas is introduced to flow non-reactive powder particles, but also has excellent heat transfer from the atmosphere to the product. Various studies have been conducted in relation to the patenting process. An et al. [6] investigated the cause of fracture due to crack generation from the pearlite interface by excessive processing such as wire drawing, when a coarse pearlite structure with a thick interface appears after patenting treatment. Gladman et al. [7] explained that in the case of pearlitic steels with eutectoid composition, the austenite grain effect is insignificant and the lamellar spacing size is important as the factor that has the greatest influence on the pearlite strength. In this study, a fluidized bed process using non-reactive powder was used as a substitute for the conventional wax bath process to improve productivity due to reduced post-treatment and to solve environmental problems. The effect of speed on microstructure and mechanical properties was investigated.

2. Experimental procedure

Table 1 Chemical composition of SAE 1078 (wt.%)

Compositions	C	Si	Mn	Cr	Ni	Cu	Fe
SAE 1078	0.808	0.241	0.104	0.015	0.015	0.012	Balance.

The material used in the fluidized bed patenting process in this study is SAE 1078 cold-rolled steel manufactured by POSCO, which is used for saw blades, knitting needles, and machine chains that require wear resistance. The chemical composition of

this material is shown in Table 1. The fluidized bed experimental furnace used in this study is a process equipment developed by itself and is divided into a heating chamber, a cooling chamber, and a fluidized chamber. The heat source is electrical and can be heated up to the maximum temperature of 1200℃ in the heating chamber, and the inner wall of the heating chamber is made of ceramic. In the case of the cooling chamber, cooling pipes and compressed air nozzles were installed for uniform cooling of the treated specimens. In particular, 30 kg of garnet powder was charged into the flow chamber, and the lower end was made in a conical shape to form a flow atmosphere, and a flow nozzle was installed at the bottom of chamber. The SAE 1078 test piece was charged into the heating zone (red area) and heated and maintained at the austenizing temperature (1000°C) for 4 minutes at a heating rate of 6°C/s. Compressed air (78.1 vol.%N2, 20.9 vol.%O2, 1 vol.%Ar) was injected at flow rates of 10, 50, and 100 l/min to cool to isothermal temperatures (460, 560, 660°C). Next, the specimen was moved to a flow chamber, maintained isothermally for 90 seconds, and slowly cooled to room temperature to perform a patenting process. After polishing the cross-section of the heat-treated specimen using SiC abrasive paper and 1μm diamond suspension, corroding it with 3% nital solution and 4% picral solution for 1 minute, and then using an optical microscope (MTDI, HRM-300) and scanning electron The microstructure was observed using a microscope (FEI Hong Kong Company, NNS-450). A micro Vickers hardness tester (Mitutoyo, HM-210B) was used to measure the core hardness of the patented specimen. The hardness value was calculated by taking the arithmetic average of the remaining values except for the maximum and minimum values by measuring 5 times with a measured load of 300 gf and a load time of 10 seconds.

Table 2 List of patented specimen and process parameter

Specimen	Austenitizing Temperature	Flow rate (compressed air)	Isothermal temperature	Isothermal time
10C-560P	1000 ℃	10 l/min	560 ℃	90 s255-259-263
50C-560P	1000 ℃	50 l/min	560 ℃	90 s 354-359-362
100C-560P	1000 ℃	100 l/min	560 ℃	90 s 371-376-378
100C-660P	1000 ℃	100 l/min	460 ℃	90 s 266-273-282
100C-460P	1000 ℃	100 l/min	660 ℃	90 s 407-414-418

3. Results and discussion

Figure 1 is a high-magnification SEM picture for comparing the lamellar spacing of pearlite of the specimen treated according to the patenting conditions. The microstructure of most treated specimens has a layered structure in which ferrite and cementite layers are repeatedly arranged. The greater the compressed air flow rate, the faster the cooling rate, and the less the degree of diffusion of carbon in the process of pearlite transformation, so average lamellar spacing of pearlite decreases (756 nm (10C-560P); 116 nm (50C-560P); 93 nm (100C-560P)). On the other hand, as the isothermal temperature increased, average lamellar spacing of pearlite tended to increase (60 nm (100C-460P); 93 nm (100C-560P); 679 nm (100C-660P)). In the microstructure of the specimen treated at 460℃, the lowest isothermal temperature, lath-phase ferrite and plate-like cementite were observed, and it was judged to be an upper bainite structure.

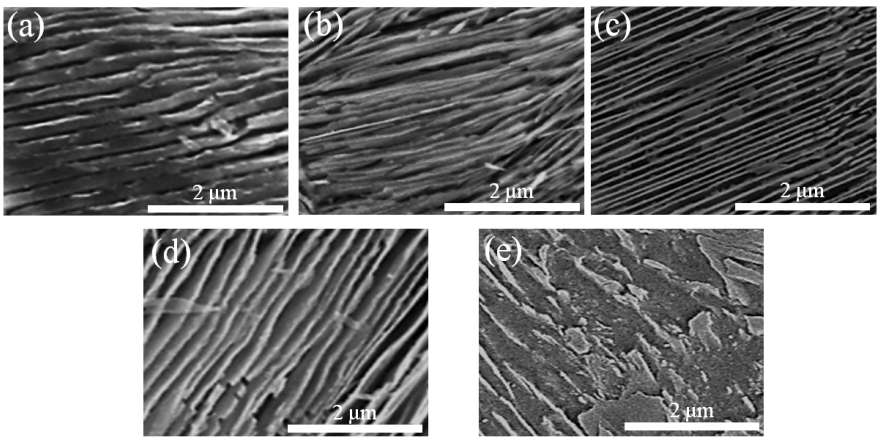

Fig 1. SEM images obtained for different patenting condition: (a) 10C-560P; (b) 50C-560P; (c) 100C-560P; (d) 100C-660P; (e) 100C-460P.

Figure 2 shows the microVickers hardness of the patented specimen after patenting treatment according to the flow rate of

compressed air up to the isothermal holding temperature after austenizing treatment. As the compressed air flow rate increases, the hardness tends to increase rapidly and then relatively slowly. The reason why the hardness of the treated specimen increases as the flow rate of compressed air increases can be confirmed through the Hall-Petch relational equation, which has a close relationship between the hardness of pearlite and the mean direct spacing in steel [8].

$$H = H_0 + k \cdot S^{-m} \quad (1)$$

k is the Hall-Petch gradient of pearlite, and H_0 is the hardness of ferrite with a mean free path. For example, Ray et al. [9] explained the proportional relationship between the interlayer spacing of eutectoid steel and pearlite hardness through Equation 1 and experimental values, and used a specific constant m = 0.5. Therefore, as the flow rate of compressed air increased, the lamellar spacing decreased and the hardness of the treated specimen tended to increase. In particular, the hardness was improved by about 40% by the bainite transformation as the isothermal holding temperature decreased. In terms of hardness, lead bath products range from 352 to 374 Hv. When looking at the hardness distribution of the patenting treated specimen according to the patenting conditions, the patenting specimen to satisfy the hardness of the lead bath product is judged to be 50C-560P, 100C-560P.

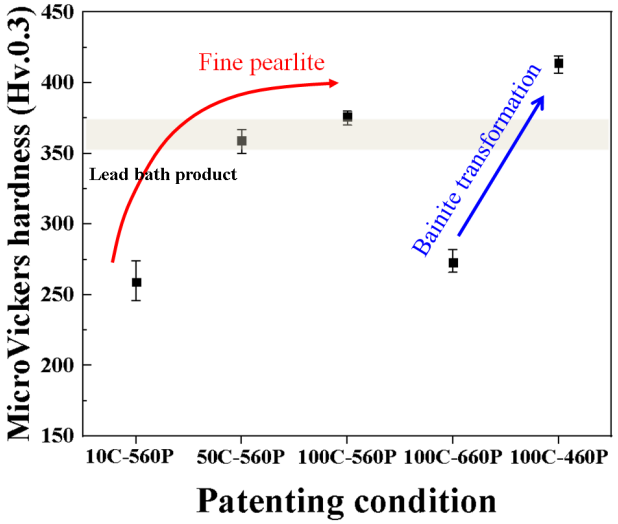

Fig 2. Micro-vickers hardness distribution according to different patenting condition.

4. Conclusions

In this study, the relationship between the microstructure and mechanical properties of SAE 1078 steel was quantitatively investigated after patenting treatment according to the cooling rate using a fluidized bed experimental furnace developed to replace the lead bath process.

1. As the flow rate of compressed air in the cooling chamber increases, the lamellar spacing of pearlite decreases because the degree of supercooling increases up to the pearlite transformation temperature.

2. Most of the specimens treated under the patenting condition had a pearlite microstructure regardless of the cooling rate, and the upper bainitic structure was observed in the specimens isothermally treated at 460 °C.

3. The hardness of pearlite tends to increase in inverse proportion to the layer spacing, satisfying the Hall-Petch equation.

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