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BAKE HARDENING OF A LOW CARBON STEEL FOR AUTOMOTIVE APPLICATIONS

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ABSTRACT

Bake hardening is an advanced processing technique to produce low carbon steels, used for car bodies, with high strength. An optimized batch annealing treatment is necessary in order to have enough carbon in solution required for bake hardening. This makes automotive bodies and panels strengthened after paint baking treatment. This effect is due to pinning of dislocations by solute carbon atoms which refers to cottrell's atmosphere. In the present work, the influence of batch annealing parameters (annealing temperature and time and cooling rate) and the amount of prestrain as well as baking temperature on bake hardenability of St14 steel was investigated.

Various annealing treatments were performed at temperatures of 680, 730 and 780 ^{o}C with the soaking times of 10, 20, and 30 minutes. Employed cooling media were furnace, still air and water. Aging index tests, 8 percent tensile prestrain and one hour baking at 100^{o}C, were carried out for assessing the bake hardenability of annealed specimens. After employing the optimum annealing cycle (780^{o}C for 30 minutes), the samples were subjected to 4, 6 and 8 percent prestrain followed by baking at temperatures of 150, 180 and 210 ^{o}C for 20 minutes. The results show that the highest hardenability will be obtained for the samples annealed at the highest time, temperature and cooling rates. Besides, the higher the prestrain and baking temperature, the higher the increment of strength due to bake hardening.

Key words: Bake hardening, St14, annealing treatment, prestrain, solute carbon

1. INTRODUCTION

Many industrial applications such as car bodies require steels with good formability and high strengths. However, theses two requirements are often contradictory. This problem can be overcome by using bake hardening (BH) technique that provides both properties for car industry. In addition, another advantage of this method is using low carbon (LC), ultra low carbon (ULC) and interstitial free (IF) steels for production of car structures instead of expensive high alloy steels. Low carbon and alloying elements content of these steels will result in good formability during press forming of car panels and high strength after paint baking treatment, respectively [1-4].

Strength increment after baking process is attributed to diffusion of carbon atoms to form an atmosphere around dislocations [5-9] that will results in pinning of dislocations and in turn increasing strength. The amount of solute carbon in the structure of the mentioned steels, which has strong effect on bake bardenability, will be influenced by annealing parameters such as annealing time, temperature and cooling rate [10].

2. MATERIAL AND EXPERIMENTAL PROCEDURE

The material used in the present investigation was St14 steel. Chemical composition of this steel is given in Table 1. Tensile test specimens were prepared from as-cold rolled sheet according to ASTM-E8 standard. Heat treatment regimes were performed on the specimens in accordance with Figure 1. Then, aging index tests, 8 percent tensile prestrain and baking for one hour in 100 ^oC, were done on the heat treated specimens. These tests were conducted to compare bake hardenability of specimens processed in different routes.

Table1. Chemical composition of St14 steel

Element	C	Si	Mn	P	S	Cr
Weight%	0.034	0.004	0.022	0.004	0.013	0.009

Element	Mo	Ni	Cu	Al	Fe
Weight%	0.002	0.031	0.031	0.041	Rem.

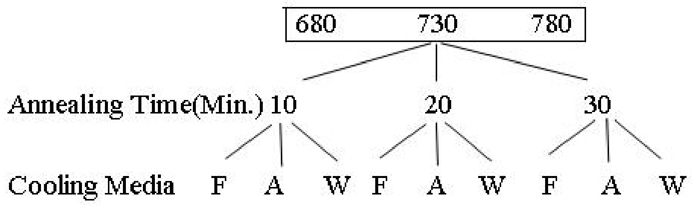

Figure 1. Heat treatment regimes used for annealing of specimens, F, A and W refer to Furnace, Air and Water as cooling media

Then, the tensile test specimens prepared from as-cold rolled sheet were subjected to optimum annealing cycle (temperature of 780 ^oC for 30 minutes) and then cooled in water. Three tensile prestrains of 4, 6 and 8 percent were performed on the annealed specimens; then, they were baked at the temperatures of 150, 180 and 210 ^oC for 20 minutes. These tests were carried out to identify the effects of prestrain and baking temperature on the strength increment due to bake hardening.

3. RESULTS AND DISCUSSION

Because of the numerous heat treatment regimes and stress-strain curves of aging index (AI) tests, only typical graphs illustrating the strength increment due to the bake hardening of specimens (annealed at 780 ^oC for 30 minute then cooled in three different media) are given in Figure 2. Referring to the results of aging index tests, Figures. 3, 4 and 5, present the effects of annealing time, temperature and cooling rate on the bake hardenability of the investigated steel, respectively. The results show that the bake hardenability of steel increases with increasing annealing temperature, time and cooling rate. It is known that the solution of cementite, major source of carbon in the structure of low carbon steels, is a thermally activated process and is controlled by diffusion of carbon atoms.

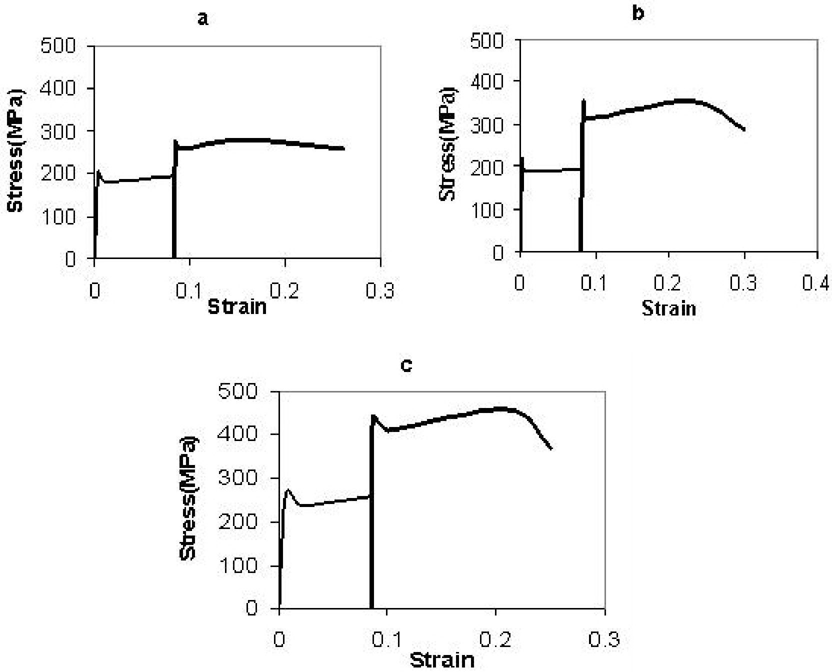

Figure 2. Aging index test results of heat treated specimens in temperature of 780 ^{o}C for 30 minutes and cooling environment:(a)furnace(b)air and(c)water

Thus, increasing the temperature and time of annealing process increases the diffusion of carbon atoms which then enhances the cementite breaking down rate. More free carbon atoms in the structure increases their interaction with dislocations and will result in higher strength through the bake hardening process [7,11] (Figures 3 and 4). As mentioned earlier about the solution of cementite during annealing, the regeneration of this phase during subsequent cooling needs the diffusion of carbon atoms in a similar manner. Hence, fast cooling will prevent long range diffusion of carbon atoms for the formation of cementite again. Consequently, most of carbon remains in solution. Therefore, the faster the cooling rate the less the volume fraction of cementite in the structure. Fig. 6 shows the SEM micrographs of specimens treated at the same condition of heat treatment and different cooling rates. As it’s clearly seen in Fig.6 (a), cementite particles are present almost on the ferrite grain boundaries after cooling in the furnace, while, these particles aren’t seen in Figure 6 (b) or the volume fraction of them is so lower.

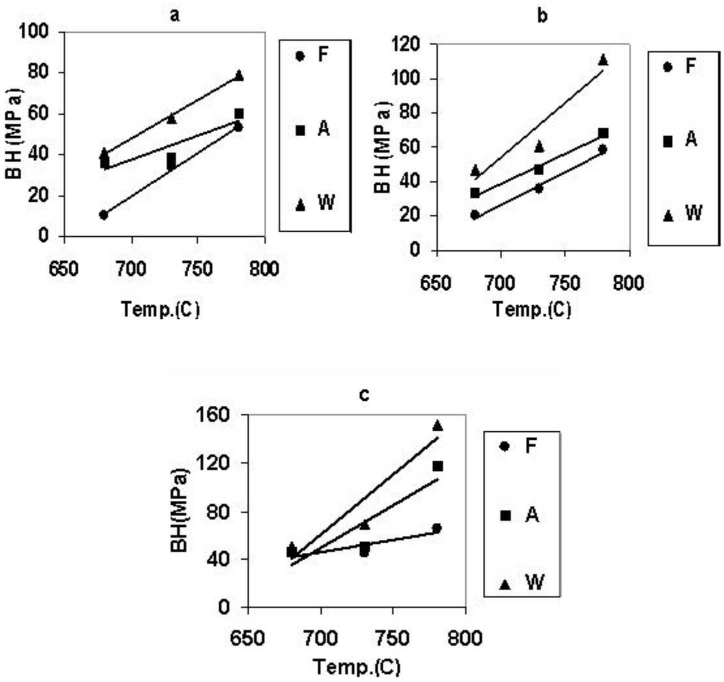

Figure 3. Effect of annealing temperature on bake hardenability in annealing times of (a) 10 (b) 20 (c) 30 minutes and different cooling environments

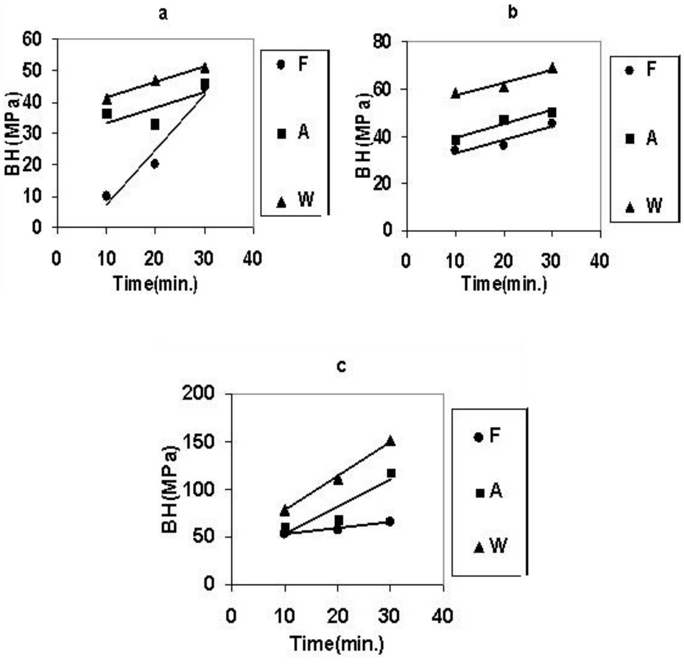

Figure 4. Effect of annealing time on bakehardenability in annealing temperatures of (a)680 ^oC (b)730 ^oC (c)780 ^oC and different cooling environments

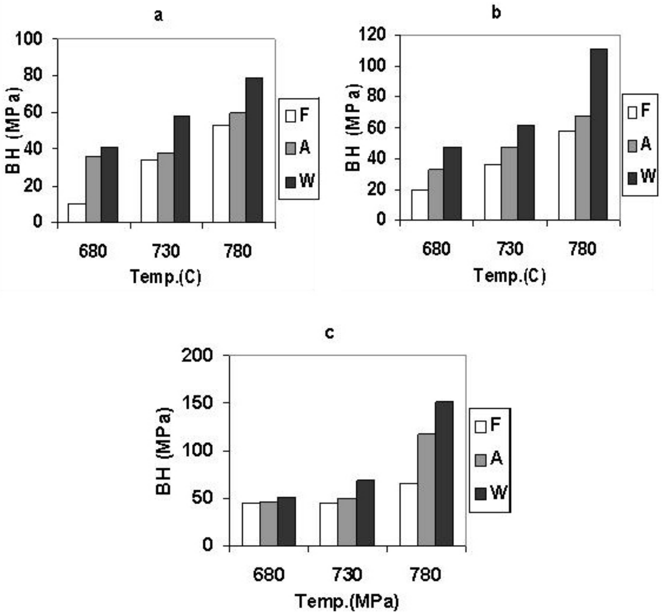

Figure 5. Effect of cooling rate on bake hardenability in different annealing times of a) 10 (b) 20 (c) 30 minutes

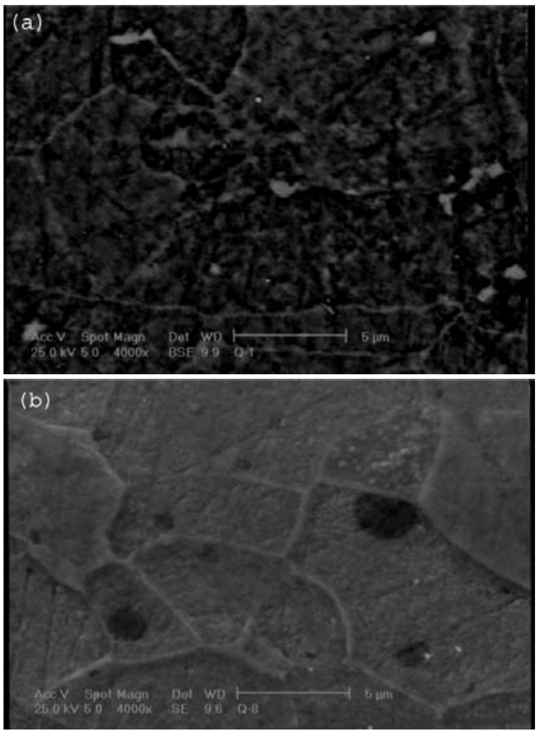

Figure 6. SEM micrographs of Specimens heat treated at 780 ^oC for 30 minutes and cooled in (a) furnace and (b) water

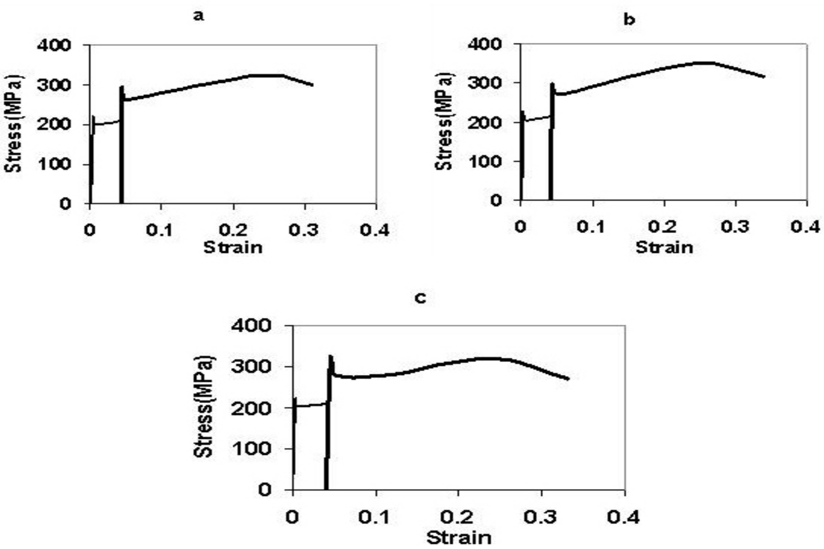

Figure 7. Stress-strain of 4% prestrained specimens before and after baking in (a)150 ^oC (b) 180 ^oC (c) 210 ^oC for 20 minutes

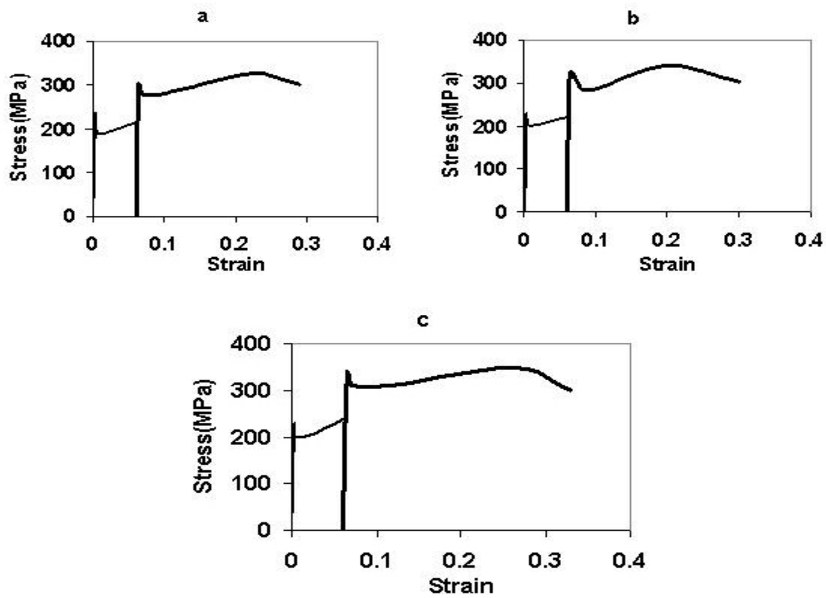

Figure 8. Stress-strain of 6% prestrained specimens before and after baking in (a)150 ^oC (b) 180 ^oC (c) 210 ^oC for 20 minutes

Figures 7, 8 and 9 offer the stress- strain curves of specimens (before and after baking at three different temperatures) with tensile prestrains of 4, 6 and 8, respectively. These graphs illustrate the strength increment due to bake hardening. The effects of prestrain amounts and baking temperatures on the strength increase due to bake hardening are given in Figures 10 and 11, separately.

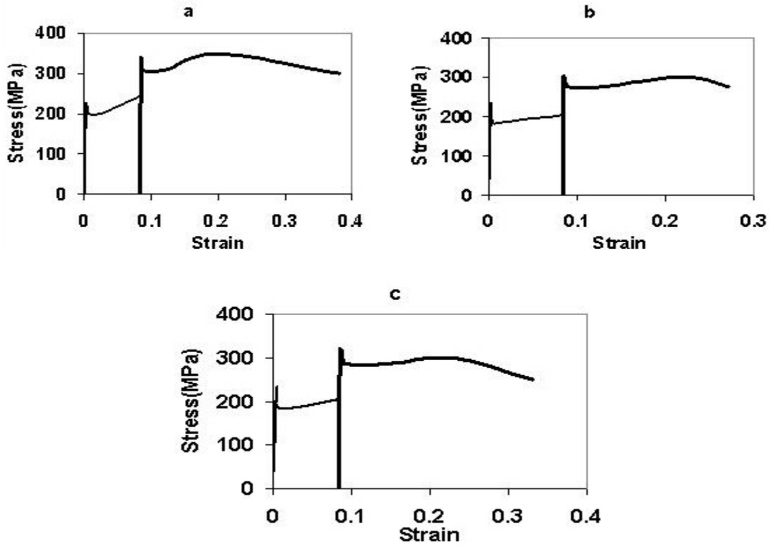

Figure 9. Stress-strain of 8% prestrained specimens before and after baking in (a)150 °C (b)180 °C (c)210 °C for 20 minutes

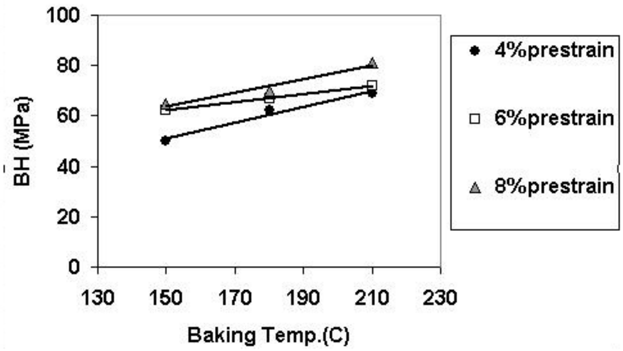

Figure 10. Effect of baking temperature on strength increment due to bake hardening in three different prestrains

Figure 10 shows that strength increment due to bake hardening increases with increasing employed prestrain. It is known that dislocations are produced during straining and their density increases with increasing prestrain amount. Therefore, the higher the dislocation density, the more the interaction between dislocations and interstitial atoms will be. Figure 5 illustrates that strength increment due to bake hardening increases with increasing the baking temperature in a linear manner. Diffusion rate of carbon atoms in the structure increases with increasing baking temperature. Thus, the interaction between dislocations and carbon atoms increases with increment of baking temperature.

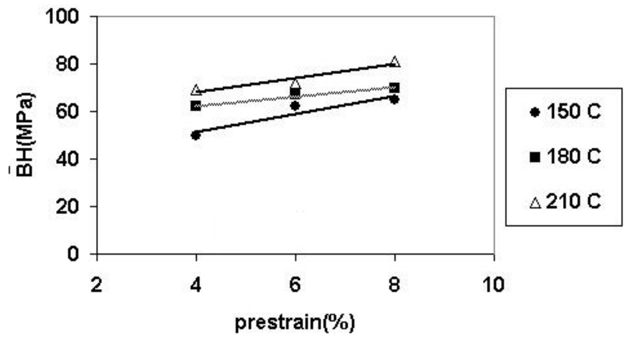

Figure 11. Effect of prestrain on strength increment due to bake hardening in three different baking temperatures

4. CONCLUSION

1- Optimization of annealing cycle of cold rolled St14 steel sheet would result in good bake hardenability.

2- Bake hardenability of St14 steel increases with increasing annealing temperature, time and cooling rate after this treatment.

3- The optimum heat treatment regime for the highest bake hardenability of St14 steel is annealing at temperature of 780 ^{o}C for 30 minutes and cooling in water.

4- Increasing prestrain amount resulted in more bake-hardening value and higher strength.

5- The higher the baking temperature the more the bake hardening effect.

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