

Effects of Austenitizing and Forging on Mechanical Properties of MIL A-12560/AISI 4340 Steel

S Herbirowo, B Adjiantoro and T B Romijarso

Research Center for Metallurgy and Materials - Indonesian Institute of Science
(P2MM-LIPI)

Kawasan Puspiptek Gedung 470, Tangerang Selatan, Indonesia

Email: satr006@lipi.go.id

Abstract. Laterite steels might be used for alternative armored steels. Their properties can be improved in various ways, such as by heat treatment. This paper reports the influences of tempering temperature on the hardness and microstructure of the modified MIL A-12560/AISI 4340 steels. Samples were austenitized at 1200, 1000, and 800°C and forged at 100, 75, and 50 tons. Mechanical properties consisted of Hardness measurement was conducted by Brinell indentation and metallographic observation was conducted by scanning electron microscopy (SEM). The results showed that increasing forging force until 100 tons can decrease hardness. The formation of the microstructure consists of tempered martensite containing ferrite and dual phase perlite. The presence of void and porous can also decrease hardness. Decreasing austenizing temperature from 1200 °C to 800°C can increase material strength and hardness.

Keyword: Laterite steel, tempering, hardness, austenitizing

1. Introduction

Armor materials having a specified goal of protection have recently found a wide use for land, air, marine and aerospace applications for civil and military purposes and also as a surface material for constructions. Recently, the heaviest threat on civil and military platforms are bullets with kinetic energy shot from modern firearms. Armor steel mentioned in this study exhibits a high level of ballistic performance against projectiles as a result of its properties, e.g. high strength, adequate toughness and good weldability [1].

Series of MIL (USA Armor Quality) are very important for many cases due to their optimal mechanical properties under kinetic and also dynamic impact to armor. On the other hand, XH129 (German Armor Quality) and Armox (Swedish Armor Quality) are known as other armor materials for protection. The mechanical properties of armor steel differ greatly in cast and heat treated forms. Quenched and tempered steels are widely used in automotive, defence, marine industries. Military steels have a martensitic/bainitic structure after being rapidly quenched. The cooling rate has to be so fast that the austenite should mainly transform within martensite and bainite ranges. In industrial applications, steels are not tough enough after a rapid quenching. So, the usable hardness-toughness balance is obtained during the tempering process by the selection of time and temperature. Parameters such as alloy design and the proper heat treatment (quenching and also tempering) are very important to determine the final properties of the product [2]. In this case, the optimum mechanical properties, for example high level of strength, hardness and also toughness, can be obtained by performing a tempering heat treatment within a certain temperature and time range [3,4]. Their properties can be improved in various ways, such as by heat treatment. This paper reports the influences of tempering temperature on hardness and microstructure of the modified MIL A-12560/ AISI 4340 steels.



2. Experimental Method

The modified laterite steel ingot with MIL-A-12560/ AISI 4340 standard was prepared in an electric induction furnace. The ingots of 5x5x10 cm in dimension were heat forged at various temperatures of 1200, 1000, and 800°C and forged at 100, 75, and 50 tons until the dimension of the ingots decreased to about 12 x 6 x 2 cm³. The square specimens of 1 cm in thickness were cut from forged alloys for chemical composition test using Optical Emission Spectrometer (OES). The chemical composition of the alloys is presented in Table 1. The specimens were austenitized at a temperature of 1050 °C for 1 hour followed by oil quench to obtain martensite structure. Then, the specimens were tempered for 1 hour. Rockwell hardness measured all heat treated samples using standard ASTM E10 and ISO 6506 for hardness Brinell scale. The samples were polished and etched using Kalling's reagent for metallographic test, and was then examined using scanning electron microscope (SEM). Energy dispersive X-ray spectroscopy (EDS) analysis was utilized to identify the carbides during tempering.

Table 1. Chemical composition in wt% of the modified Laterite steel in this study

Steel Type	C	S	P	Mn	Si	Cr	Mo	Ni	Fe
13Cr3Mo3Ni	0.204	0.0075	0.01	0.309	0.24	0.452	0.001	1.564	Bal.

3. Results and Discussion

The effect of austenizing temperature of the modified MIL A-12560 steel on hardness value is shown in Figure 1. As can be seen, the hardness decreased from the highest austenizing temperature at 1200 until 800 °C. The initial drop in hardness was due to the precipitation of M₃C which causes the softening of the martensite because of carbon depletion [5]. It can be observed from Figure 1 that the highest hardness of modified MIL-A-12560 steel in temper condition was 205.03 HB at 800 °C. The decreasing hardness in the range of 50 to 100 tons can be attributed to the secondary metal forming phenomenon. It can also be seen in Fig.1 that the hardness decreased along with the increase at austenizing temperatures ranged from 800 to 1200 °C. It could occur due to the M₇C₃ carbides started to coarsen and partially transform to M₂₃C₆ carbides [6]. The reason for variations in properties can be attributed to the combined effects of (i) hardening: due to a transformation of the retained austenite and formation of fine precipitates; and (ii) softening: due to a reduction in internal stresses, decrease in dislocation density within martensite lath, and formation of reversed austenite as described in other report [7]. While tempering at higher temperatures, quenched martensite formed while the annealing solution starts softening which leads to the elimination of internal stresses, decrease in dislocation density, and an occurrence of the retained austenite [8].

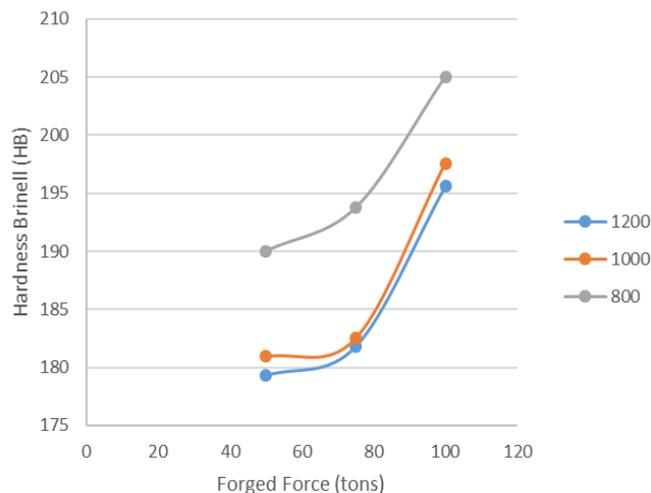


Figure 1. The hardness rate of the modified steel at various austenizing temperatures.

Figure 2 shows SEM microstructure of various austenizing temperatures at 1200, 1000, and 800 °C

in a forging force of 75 tons. It can be observed that the microstructure of tempered laterite steel generally contain martensite lath, and carbide. The carbide formed after the tempering process was not so clear to see. These types of precipitates were mainly located in the matrix and martensitic lath structure. These thermally stable fine precipitates enhanced the long term creep resistance by impeding movement of mobile dislocations, prior austenite grain boundaries, martensite lath and subgrain boundaries, and restrict fine grain structure from recrystallization. For a constant normalizing time of 2 h, prior austenite grain size and martensite lath size increased along with the increasing austenizing temperatures of 800 °C –1200 °C, as shown in Figure 2a–c. The as-austenitized (1200 °C for 2 h) microstructure had hard martensitic lath structures with high dislocation density, as observed in Figure 2b and c. Similarly, for constant austenizing temperature of 1000 and 800 °C, the martensite lath size and prior austenite grain size increased along with the increasing forged force of 100, 75 and 50 tons.

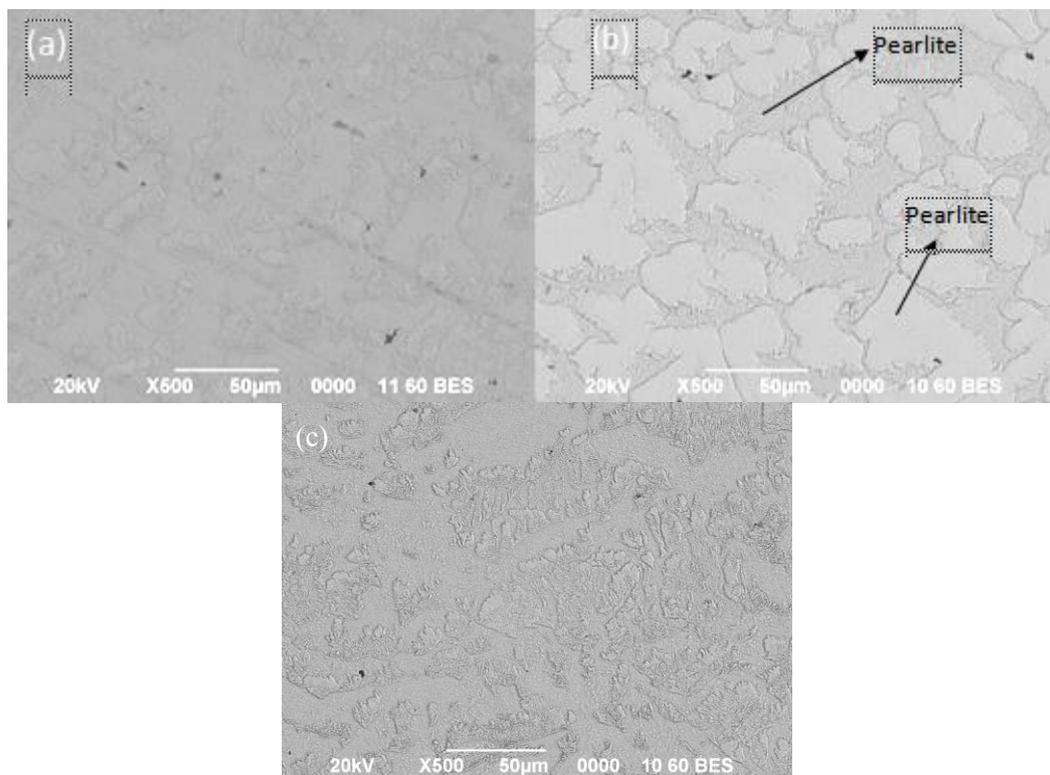


Figure 2. SEM micrograph of specimens that forged at 75 tons and austenitized at (a) 1200, (b) 1000, and (c) 800 °C.

During this kind of precipitation, the hardness of steel decreased as a result of the transformation from martensite to ferrite structure. However various carbide precipitates such as MC, M₂C, M₇C₃ can be formed with an addition of some alloying elements that have a strong affinity to carbon at high tempering temperatures. As a result, an increase in hardness can be determined and called as secondary hardness. Such increase in hardness characteristic was obtained by a complex precipitation hardening. The precipitation characteristic of some carbides formed by various alloying elements during tempering is shown in Figure 2. As seen from the figure, the formation temperatures of formed carbides increase along with the increase of the carbide stability [9-11]. Secondary hardness precipitates form preferentially upon dislocations and lath boundaries in lath-type martensitic matrix. The maximum value of secondary hardness can be obtained by precipitation of several semi-coherent nanometer sizes, while the density of M₂C is two times of MC carbides at the initial stage of over-tempering and it provides the basis of matrix hardness. This kind of precipitate grows up rapidly and its number decreased depending on its low thermo-dynamical stability during tempering.

Finally the relationship between the amount of impact strength and their forged force has been represented in Figure 3. As it can be seen from the figure, the impact strength decreased and was almost linear for the increasing forged force relationship existed for several steel based materials [12,

13]. That is why it was expected that carbides dissolve in the matrix at high austenitisation temperatures and precipitate in a fine form as secondary carbides at lower temperatures during tempering. To obtain such a microstructure, the steel must be austenitized so that the carbides of the weak and semi-strong carbide forming elements dissolved. At this heat treatment, the material was hold at the temperatures of 800-1200 °C for a certain period of time. After this, a tempering heat treatment followed at a temperature of up to 600 °C whereas the carbon and carbide forming elements dissolved in the matrix form fine dispersed secondary carbides in the solid solution and cause an enhancement of hardness and strength. To obtain a high hardness rate during tempering, it was desired that high amounts of elements like Mo and Cr should dissolve. [14].

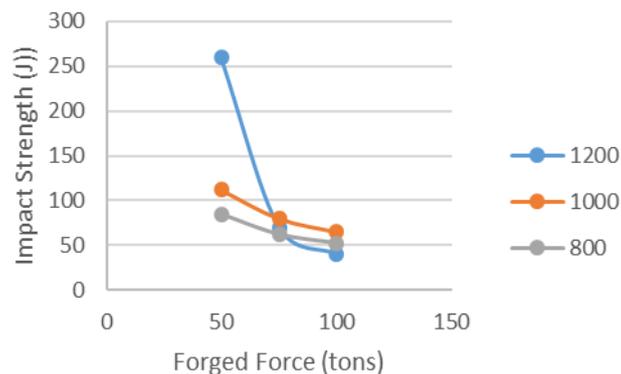


Figure 3. The impact strength with various forged

4. Conclusion

The austenitizing temperature could strongly affect the hardness and microstructure of the modified MIL A-12560/ AISI 4340 steel. The increasing forged force can affect the impact strength of the modified MIL A-12560/ AISI 4340 steel. The highest hardness was obtained at 800 °C. The formation of the microstructure consists of tempered martensite containing carbides $M_{23}C_6$. Increasing forged force from 50 to 100 tons can decrease hardness and impact strength properties.

5. References

- [1] Karagöz Ş, Yılmaz A, Atapek H 2007 Development of Quenched & Tempered Steel as Armor Materials Through Alloying and Heat Treatment *Military Science & Intelligence Magazine* p.42-45
- [2] Atapek H 2006 Development of an Armor Steel along the Principles of Physical Metallurgy & Its Characterization', Master Thesis, Kocaeli University, Institute of Applied Science, Turkey
- [3] Smoljan B 2007 Prediction of Mechanical Properties and Microstructure Distribution of Quenched and Tempered Steel Shaft *Journal of Materials Processing Technology* **175** p. 393 -397
- [4] Matsubara H, Osuka T, Kozasu I, Tsukada K 1972 Optimization of Metallurgical Factors for Production of High Strength, High Toughness Steel Plate by Controlled Rolling *Transactions ISIJ* **12** 435 -443
- [5] Balan K P, Reddy A V and Sarma D S 1998 Austenite Precipitation During Tempering In 16Cr-2Ni Martensitic Stainless Steels *Scr. Mater.* **39** 7 pp. 901–905
- [6] Isfahany A N, Saghafian H and Borhani G The effect of heat treatment on mechanical properties and corrosion behavior of AISI420 martensitic stainless steel *J. Alloys Compd.*, **509** 9 pp. 3931–3936, 2011.
- [7] Krishna C, Kumar N, Jha A K, Pant B and George K M 2015 Microstructure and Properties of 15Cr-5Ni-1Mo-1W *Steel Research* **86** 1 pp. 51–57
- [8] Dening Z, Ying H, Wei Z and Xudong F 2010 Influence of Tempering Process on Mechanical Properties of 00Cr13Ni4Mo Supermartensitic Stainless Steel *J. Iron Steel Research* **17** 8 pp. 50–54
- [9] Honeycombe R W K 1981 Steels – Microstructure and Properties *Metallurgy and Materials*

Science Series, UK

- [10] Karagoz Ş, Yılmaz A, Atapek H 2006 Development of Quenched and Tempered Sheet Steel Products', *13th International Metallurgy & Materials Congress Istanbul-Turkey*
- [11] Karagoz Ş, Andren H –O 1992 Secondary Hardening in High Speed Steels *Z. f. Metallkunde* **83**, 386-394
- [12] Fischmeister H, Karagoz Ş, Andren H –O 1988 An Atome Probe Study of Secondary Hardening in High Speed Steels *Acta Metall* **36** 817-825
- [13] Karagoz Ş, Fischmeister H F, Andren H-O, 1992 Cai-Guang Jun Microstructural Changes During Overtempering of High Speed Tool Steels *Metall. Trans.* **23A**, 1631-1640
- [14] Karagoz Ş, Atapek H, Yılmaz A 2007 Development of QT Steels as Armour Materials *4th Iron-Steel Congress Zonguldak-Turkey*

Acknowledgements

This paper is part of development of high strength material for laterite steels. The authors would like to be obliged by the Research Center for Metallurgy and Material of Indonesian Institute of Sciences for providing laboratory facility and funding this research.