AMM-1016

Determination of Austenitizing and Tempering Temperatures for 65Mn Steel To Improve Mechanical Properties of Disc Ploughs

Surawut Sangjun[1,*], Kumpanat Sirivedin[1], Satian Niltawach[1], Nattapon Ratanamalee[2]

[1] Materials and Metallurgical Engineering Program,
Department of Mechanical and Process Engineering.
The Sirindhorn International Thai-German Graduate School of Engineering (TGGS),
King Mongkut's University of Technology North Bangkok, Bangkok, Thailand
[2]Research and Development Division, Iron and Steel Institute of Thailand, Bangkok, Thailand
*Corresponding Author, E-mail address: *surawut_ton@hotmail.com

Abstract:

Steel disc ploughs used for soil cultivation demand high strength and good toughness. In Thailand, high-manganese carbon steel of 65Mn grade (ASTM: 1566) is commonly chosen to produce the discs, due to its high harden-ability and versatile tempering characteristics. In production, temperatures for Austenitizing, Stamping, Quenching and Tempering processes are pre-determined and put into practice. The aim is to ensure an appropriate martensitic microstructure. However, it was found in real practice that after the mentioned processes, some of the discs appeared wavy at the edge. Investigation revealed that the microstructure of the defective discs was fully martensitic at both center and edge; whereas for conformal counterparts, there were found martensite at the edge and some retained austenite near the center. This phenomenon indicated that retained austenite mitigated waviness because the volume increase from martensitic transformation was offset by the retained austenite. Dilatometer was employed to determine a range of austenitizing temperatures, such that after quenching, martensite as well as retained austenite was obtained. Heating furnace then came in use at different tempering temperatures to convert the retained austenite together with the as quenched martensite into tempered martensitic microstructure. This work has concluded that for 65Mn grade steel, 850 ^{o}C is an appropriate austenitizing temperature; and that 420 ^{o}C is a suitable tempering temperature. The combination of these 2 parameters produces strong and tough disc ploughs with “42 HRC” hardness number and “16.00 J” impact energy.

Keywords: Disc plough, stamping process, retained austenite, martensite, impact energy

1. Introduction

For modern farming system in Thailand, disc ploughs are becoming popular among farmers. The discs are used primarily to till the land [1].

Disc ploughs of grade 65Mn steel are used in hard and tough conditions. The desired mechanical properties are obtained by hot stamping process, which involves heating, forming, quenching and tempering [2]. However, it was found that after hot stamping, oil quenching and tempering, some of the discs appeared wavy at the edge. The mishap was thought to have been caused by too high austenitizing temperature and also too fast cooling rate.

The objective of this study is to analyze the parameters which have impact on this problem, as well as to determine a suitable temperature range for hot stamping and tempering so as to improve the mechanical properties of the disc ploughs

2. Experiments

2.1 As-received Materials Characterization

Chemical composition analysis was carried out on as-received grade 65Mn steel using Optical Emission Spectrometer. The result is displayed in **Table 1**. The steel was also metallographically examined.

2.2 Austenitizing Temperature Calculations

2.2.1 Austenitizing temperature can be estimated using equation (1) below.

A_{c3} (^{o}C) = 947 – 264 $\sqrt{\%C}$ – 8%Mn + 45%Si + 5%Cr +74%Al + 10%Mo – 23%Ni +94%V **(1)** (wt %)

2.2.2 It can also be accurately determined by dilatometer (Bahr Thermoanalyser, DIL805 A/D) equipped with linear thermal expansion detector.

2.3 Metallographic Comparisons

So as to compare the microstructures between defective (NG) products and conformal (G) counterparts, metallographic examinations using Inverse Optical Microscopy were carried out. The comparison was done between the microstructure at the edge and that in the center of the disc.

2.4 Heat Treatment Procedures

The appropriate austenitizing temperature and tempering temperature were obtained using the following approaches.

First, employ a Bahr dilatometer as in Section 2.2 **(2.2.2).** Cylindrical dilatometer specimens 10 mm in length and 5 mm in diameter were machined from 65Mn steel bar having a diameter of 5 mm nominal. This is to find appropriate austenitizing temperature. And then it compares with conformal products which are gathered data from real process.

Second, Charpy specimens of size 10x55x5 mm^3 were made from 65Mn steel bar. These specimens would undergo treatment in a tempering furnace, prior to going for Vickers hardness test and also for Charpy Impact test.

The Dilatometer was employed to estimate appropriate tempering temperature range, while the furnace was used to choose the best tempering temperature.

Dilatometer and tempering furnace procedures were carried out as in **Figure 1**.

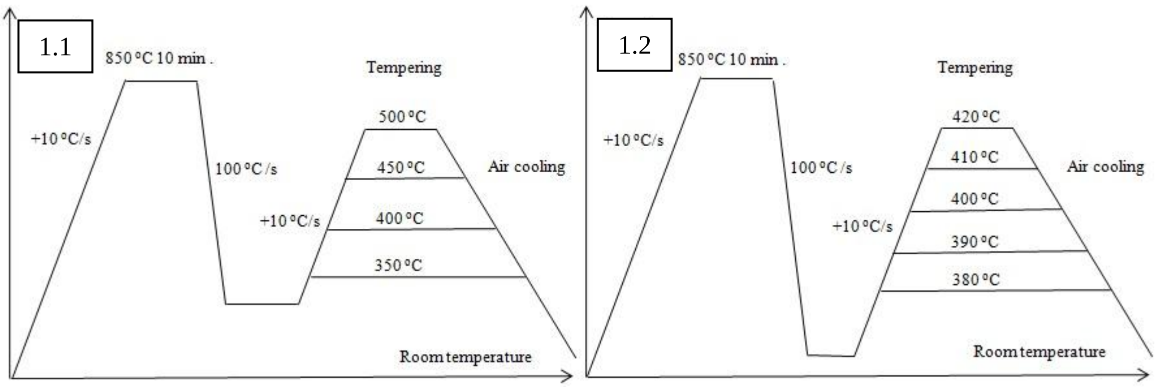

Figure 1: Schematic thermal (quenching and tempering) schedules applied to the samples in Dilatometer (1.1) and Tempering Furnace (1.2)

Table 1: Chemical Composition of 65Mn Steel (in wt %)

Grade	C	Mn	Si	Cr	Al	Mo	Ni	V	Fe
65Mn	0.526	1.113	0.312	0.015	0.017	0.001	0.005	0.002	Bal.

3. Results

3.1 As-received Materials Characterization

The chemical composition of 65Mn steel grade is showed in **Table 1**. It has high carbon and high manganese contents with some alloying elements present in small insignificant quantities.

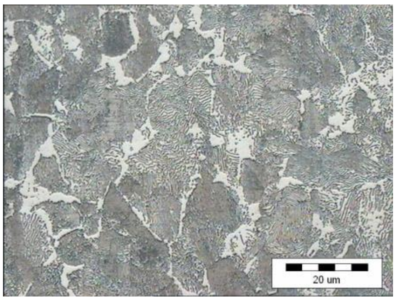

Figure 2: Optical microstructure obtained from as-received 65Mn steel, etched in 2% natal (500x).

The steel microstructure is showed in **Figure 2** consisting of proeutectoid ferrite (white, α - mixed crystal) and pearlite (brown, eutectoid cementite).

3.2 Austenitizing Temperature

The temperature can be calculated from Equation (1) as 762 $^{\circ}$C. So as to ensure that the steel microstructure is fully austenitic, an extra 50 $^{\circ}$C is added on to the calculated figure making it **812 $^{\circ}$C.** Alternatively, austenitizing temperature can also be obtained using the dilatometer result as displayed in **Figure 3** from which the austenitizing temperature is measured at **780 $^{\circ}$C.** After their efforts to finding appropriate austenitizing temperature by using 2 values above and comparing it temperature with conformal products which are gathered data from real process. Therefore the 850 °C is suitable value for the austenitizing temperature in Figure 1.

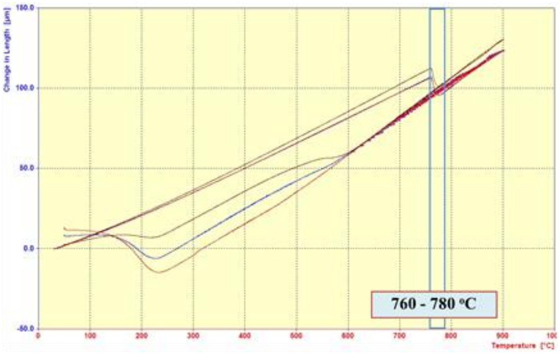

Figure 3: Austenitizing temperature obtained from as-received 65Mn steel, heating rate at 10 °C/s to 900 °C using a dilatometer

3.3 Metallographic Comparisons

The microstructures of conformal and defective discs at the edges as well as at the centres are showed in **Figure 4**. For the defective discs, it is fully martensitic both at the edge (A) and also at the center (B); as for the conformal, the microstructures comprise of fine- grained martensite at the edge (C), and some retained austenite in martensitic matrix at the center (D).

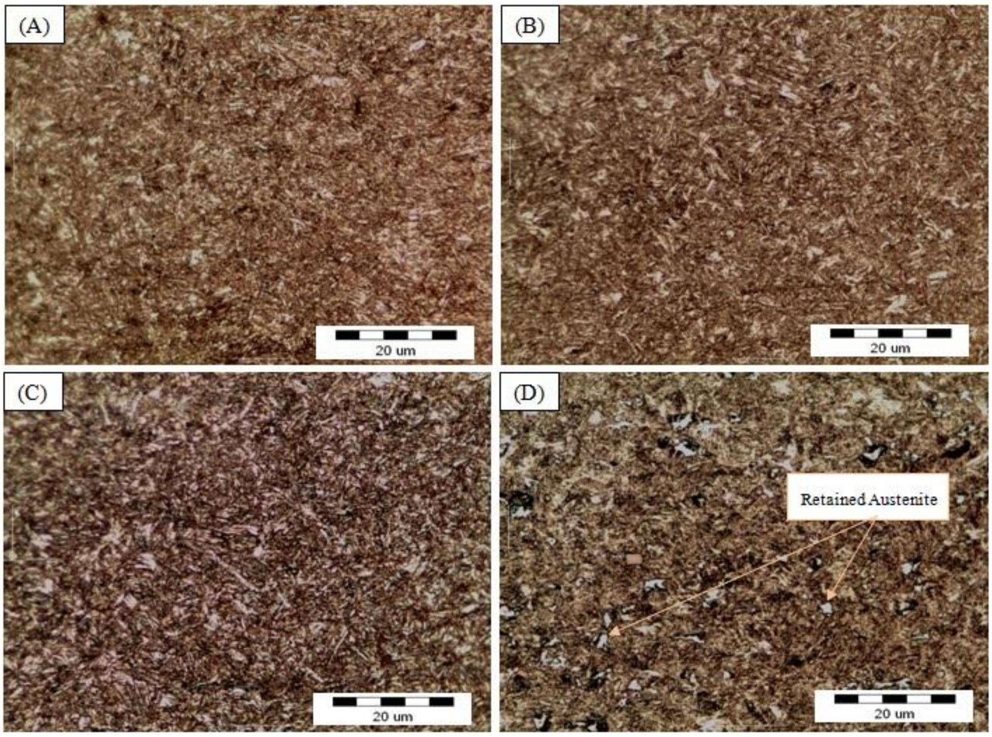

Figure 4: Optical micrographs of defective discs: at the edge (A) and at the center (B).
Optical micrographs of conformal discs: at the edge (C) and at the center (D).

3.4 Effect of tempering temperature on micro-structure, hardness and Impact Energy

Because microstructure after quenching needs retained austenite so as to prevent edge waviness of the disc, appropriate tempering temperature to transform retained austenite to tempered martensite needs to be known. Martensitic microstructures of specimens after heating to 850 ^{o}C for 5 min and quenching with cooling rate 100 ^{o}C are showed in **Figure 5**. (5.1) Shows microstructures from dilatometer (63 HRC) and (5.2) displays microstructure from heating furnace (61 HRC).

From dilatometer, hardness values depend on tempering temperature as show in **Figure 6**. The hardness decreases from 49 to 38 HRC with increasing tempering temperature from 350 to 500 ^{o}C. From tempering furnace, hardness and impact energy are also seen to depend on temperature as depicted in **Figure 7**. Hardness values slightly decrease from 48 to 42 HRC with increasing tempering temperature from 380 to 420 ^{o}C. As for impact energy values, they increase with increasing tempering temperature from 6.34 J to 16.00 J.

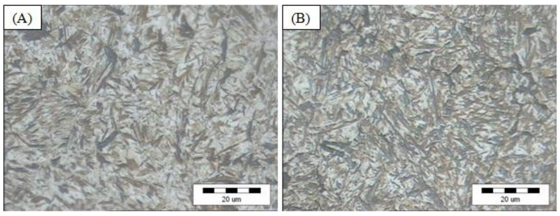

Figure 5: Optical microstructures obtained from oil-quenched at 850 ^{o}C at cooling rate 100 ^{o}C/s, (5.1) from dilatometer and (5.2) from heating furnace.

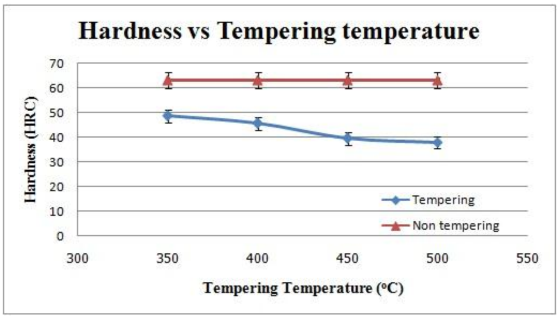

Figure 6: Effect of tempering temperature on hardness from dilatometer specimens

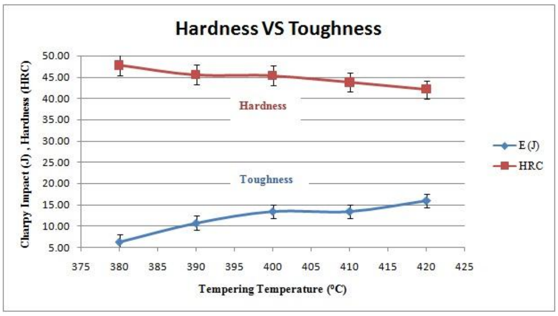

Figure 7: Effect of tempering temperature on hardness and impact energy from heating furnace specimens

4. Discussions

Chemical composition and microstructure of the as-received material are to be considered first, because they are the foundation for this study. Second, austenitizing temperature has to be determined. When sample is heated from room temperature, thermal expansion occurs continuously up to Ac_1, where it transforms from body-centered cubic (BCC) ferrite to face-centered cubic (FCC) austenite. When sample is heated from room temperature, change in length is increase. So called linear thermal expansion continuously up to Ac_1 (where body-centered cubic (BCC) ferrite firstly transforms to face-centered cubic (FCC) austenite). Then the change in length decrease from Ac_1 to Ac_3 (where BCC ferrite fully transforms to FCC austenite). After that the change in length returns to increasing above Ac3 (fully martensite transformation) [3]. When austenite is cooled quickly, martensite forms. The transformation of austenite (FCC) to martensite (BCT) causes an increase in volume, which influences the stress distribution during quenching. Only complete transformation behavior allows a prediction of different phase, residual stresses and the distortion of the work-piece [4].

The microstructures are compared to find out the root cause of this problem. Microstructures at edge (A) and at center (B) of the defective disc are put side by side to those at edge (C) and at center (D) of the conformal disc shown in **Figure 4**. It is observed that for ‘bad’ discs, the microstructures comprise of fine grained martensite both at the edge and at the center; while for “good” discs, there is martensite at the edge, and martensite plus some retained austenite at the center.

It should be noted that when there is a volume increase in transforming austenite to martensite, plastic deformation also occurs [5]. This occurrence which is called transformation plasticity effect causes development of stresses during the hardening of the disc [6].

So the overall volume increase for the conformal disc is lower than that of the defective disc, even though the edges of the 2 discs are found fully martensitic. Because the edge is thin, it is very sensitive to the volume increase at the center. The edge distortion is to mitigate the effect of volume increase. Presence of retained austenite at the center thus helps distortion at the edge.

The retained austenite is to be further transformed into martensitic microstructure by tempering. Furthermore, the as quenched martensite is too hard and brittle to be used in service. Tempering has to be carried out in order to improve the disc’s toughness and also to transform retained austenite to bainite or martensite. Tempering comprises of heating the hardened disc to temperature below Ac_1 which is 700 ^{o}C for 65 Mn steel. For this study, 350 ^{o}C – 550 ^{o}C tempering temperature is used in dilatometer to ensure that hardness after this process is above 40 HRC per factory requirement. From **Figure 6**, the hardness value is 46 HRC at 400 °C tempering temperature. To be more precise, tempering temperatures at 380, 390, 400, 410 and 420 °C are carried out in heating furnace. The hardness values and Impact energy values are showed in **Figure 6**. From **Figure 7**, the hardness values slightly decrease from 48 to 42 HRC with increasing tempering temperatures from 380 to 420 °C; whereas the Impact energy values increase with increasing tempering temperatures from 6.34 J to 16.00 J. The purpose of tempering process is as follows. Since the chemical composition of steel after hardening corresponds to that before quenching, all microstructure components (martensite and retained austenite) are thermo-dynamically instable. Through tempering, a state nearer to equilibrium is achieved [7]. Hence, as quenched martensite is transformed into tempered martensite; retained austenite into martensite; both entities are more stable with higher toughness than as quenched martensite.

5. Conclusions

5.1 The volume increase is maximum when austenite (FCC) transforms to martensite (BCT) causing a rapidly increase in stress distribution during quenching and distorted of the edge. To mitigate edge distortion of the disc, it is necessary to have retained austenite and to avoid full martensite microstructure.

5.2 Increasing tempering temperature from 380 to 420 °C, hardness is decreased from 48 to 42 HRC. On the contrary, impact energy is increased from 6.34 to 16.00 J. The conclusion is that tempering at 420 °C; the result is a good combination of hardness and impact energy at 42.00 HRC and 16.00 J respectively.

6. Acknowledgments

This work was financially supported by Research and Development Division, Iron and Steel Institute of Thailand. Authors are grateful to K W Metal Work Co., Ltd. for providing experimental steel.

7. References

[1] ASAE Standards. Agricultural Engineers Yearbook of Standards, 45th Ed. American Society of Agricultural Engineers, St. Joseph, MI-49085, USA. 1998.

[2] H. Karbasian∗, A.E. Tekkaya. 210, s.l. : A review on hot stamping. Journal of Materials Processing Technology, 2010. p.2103-2118.

[3] Anil Kumar Sinha, Bohn Piston Division. Defecs and Distrotion in Heat-Treated Parts. ASM Handbook, Volume 4 : Heat Treating, p 610 -619

[4] Neubauer, I., Hubner, K., Wicke, T., 2008. Thermo-mechanically coupled analysis: the next step in sheet metal forming simulation. In: 1st International Conferenceon Hot Sheet Metal Forming of High-Performance Steel, Kassel, Germany, pp.275–283V

[5] P.G. Greenwood and R.H. Johnson, *Proc. R. Soc.,* Vol A283, 1965, p 40

[6] B.L. Josefson, *Mater. Sci. Technol.,* Vol 1 (No. 10), 1985, p 904-908

[7] W.Bleck. *Technical Heat Treatments,.* Aachen, Germany : s.n., *p 212 - 214*