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Research Article

Surface Treatment Evaluation of Induction Hardened and Tempered 1045 Steel

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Abstract

Rod-shaped samples of SAE-AISI grade 1045 steel with a ferrite and pearlite structure in the as received condition were subjected to induction hardening to increase the hardness of the surface layer. The heat treatment process was carried out using induction heating with five different peak temperatures: 800^{0}C, 900^{0}C, 1000^{0}C, 1100^{0}C and 1200 ^{0}C for 2 s, before water quenching. The chemical composition and the microstructures of these samples were characterized by spectrometry and optical microscopy. The microhardness of the surface of each samples was measured and preliminary tensile testing was conducted. The results showed the formation of a significant hardened case due to the formation of martensite, while the core retained its original ferrite-carbide microstructure and was softer and tougher. Tempering was carried out 300^{0}C, 500^{0}C and 700^{0}C in order to stress relieve the quenched samples and to increase the toughness of the steel case with an acceptable reduction in hardness.

Keywords: *Induction hardening, 1045 steel, Case depth, Tensile strength, Quenching and Tempering.*

1. Introduction

Normalised 1045 steel has a microstructure of ferrite and pearlite with volume fractions of about 0.4 and 0.6, respectively. Full softening can be achieved by a spheroidising treatment below the A_1 temperature (~< 700^{o}C) and in this condition the hardness is typically in the range about 120-140 HV and the steel is readily machinable. However, this steel grade can be hardened by quenching in oil or water after an austenitising heat treatment to produce a martensitic structure that is then tempered to counter the brittleness imposed by quenching (Krauss, 1977).

Rail clip, shafts and gears are typical applications of 1045 steel. In order to have the necessary wear resistance, the steel has to have a high surface hardness. Therefore, a surface treatment, such as induction hardening is a very important process for achieving a suitable surface hardness for wear resistance applications (Lakthin, 1979). This type of low alloy medium carbon steel has not been extensively studied for the development of wear resistance by using induction hardening, particularly in relation to variable tempering treatments to control the toughness of the quenched steel.

The heat treatment process involves heating and holding above the critical temperature range to produce a fine grained austenitic structure. This treatment is followed by fast quenching using water or oil. A slower rate can be obtained by air cooling, but the relatively low hardenability of the alloy will ensure that a completely martensitic structure will not be achieved. The martensite structure produced by rapid quenching is hard and brittle, and prone to cracking under service conditions. Therefore, a tempering process needs to be carried out after the hardening process. Tempering involves heating and holding at a temperature below the A_1 to avoid reformation of austenite. Tempering relieves internal stresses resulting from quenching and increases the toughness, with an accompanying loss in strength and hardness (Thelning, 1974).

The induction hardening mechanism is based on induced current flow in the steel conductor, due to a magnetic field surrounding it. If the magnetic flux is produced by a high frequency current, then eddy currents near the steel surface are significant, and rapidly raise the temperature to the austenitising range from which it is quenched to obtain martensitic transformation in the case of the steel component (Polar, 2009).

The purpose of this study was to evaluate the surface hardness and case depth in rod samples of 1045 steel subjected to induction hardening, followed by tempering.

2. Experimental Methods

2.1 Induction hardening

The induction hardening of 1045 steel was carried out in the Heat Treatment Department of the Army (Steel Industry) in Bandung, Indonesia. The heat treatment was conducted using induction hardening temperatures of 800^{0}C, 900^{0}C, 1000^{0}C, 1100^{0}C and 1200^{0}C with a heating time of about 2 s at each temperature, followed by water

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quenching for 55 s. The details of the induction hardening process are: voltage: 7.5V, power: 8.5kW, frequency: 50Hz, current: 5A, inductor speed: 3.5mm/s, 4mm/s, 4.5mm/s, 5.5mm/s and 7mm/s and pre-heating: 2s. The sample used was a rod of 30 mm diameter and 120 mm length.

2.2 Tempering

After the hardening process, tempering was carried out at temperatures of 300^0C, 500^0C and 700^0C for 30 minutes in a tempering oven, followed by air cooling.

2.3 Characterisation of 1045 Steel

The initial hardness measurement for the raw material was conducted using a Brinell hardness testing machine with a load of 750 kg. Then microhardness measurements were made at intervals of 0.50 mm through the surface layer of induction hardened 1045 steel using a Vickers hardness testing machine with a load of 5 kg. Cross-section samples of the rod were then mechanically polished and etched in a 2% nital solution to reveal the microstructure by optical microscopy.

3. Results

3.1 Nominal Composition

The composition of the 1045 steel was determined by spectrometry, Table 1.

Table 1 Nominal compositions (wt%) of the SAE-AISI 1045 steel

(%)	C	Si	Mn	P	S
1045	0.44	0.26	0.77	0.03	0.05

3.2 Optical Microscopy of 1045 Steel

The microstructure on the 1045 steel substrate had a ferrite-pearlite appearance, while the surface layer consisted of a martensitic structure. Fig. 1(a) shows the microstructures resulting from hardening without tempering and the other microstructures represent tempering at 300^0C, Fig. 1(b); tempering at 500^0C, Fig. 1(c); and tempering at 700^0C, Fig. 1(d).

Fig. 1(a) shows an acicular structure that is due to the formation of martensite with mixed plate and lath morphologies. With increasing tempering temperature the acicular structure becomes less evident as the martensite progressively decomposes to a mixture of ferrite and carbide, Figs. 1(b-d).

3.3 Microhardness of Surface Layer of Hardened 1045 Steel

The microhardness of the surface layer of 1045 steel subjected to an induction hardening temperature of 1200^0C was about 685 HV. This hardness level is consistent with that of untempered martensite in steel containing 0.45 % C. In comparison, 464 HV was measured for a hardening temperature 800^0C. In this case the peak temperature did not produce a fully austenitic structure and therefore a limited volume fraction of martensite was produced on quenching with the untransformed matrix consisting of coarsened grains of ferrite and carbide.

The microhardness of the surface layer of 1045 steel after tempering at 300^0C was about 439 HV for a hardening temperature of 1200^0C compared with 344 HV after tempering at 500^0C and 223 HV after tempering at 700^0C. The hardness of the unaffected substrate was about 130 HV.

3.4 Hardening and Tempering Treatments

Fig. 2, shows that the surface hardness increased steeply with increasing hardening temperature, but flattened out above about 1100^0C. The effect of tempering is shown by Fig. 3, the surface hardness decreased with increasing tempering temperature. The effect of tempering on the tensile strength is recorded in Fig. 4. The tensile strength decreased as the tempering temperature increased from 300^0C to 700^0C.

3.5 Case Depth

Fig. 5 shows that the case depth increased with hardening temperature. Fig. 6 indicates that the case depth is influenced also by the speed of the inductor. The case depth was shallower as the inductor speed increased.

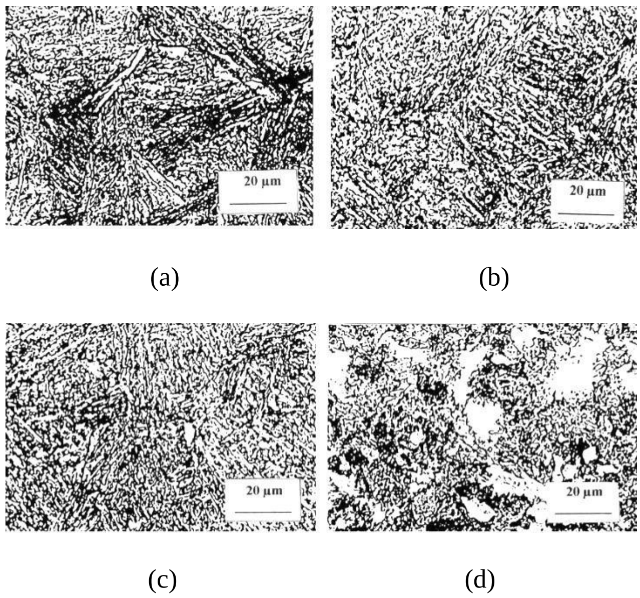

Fig.1 Optical micrographs of samples of 1045 steel subjected to a hardening temperature of 1100^0C, followed by water quenching. (a) Untempered, (b) tempered at 300^0C, (c) tempered at 500^0C and (d) tempered at 700^0C.

4. Discussion

The results from the tests conducted for induction hardened 1045 steel showed that a lower hardening temperature resulted in incomplete martensite formation and a reduced surface hardness. A completely martensitic structure was obtained for the tests conducted at 1100^{0}C, as shown in Fig. 1(a).

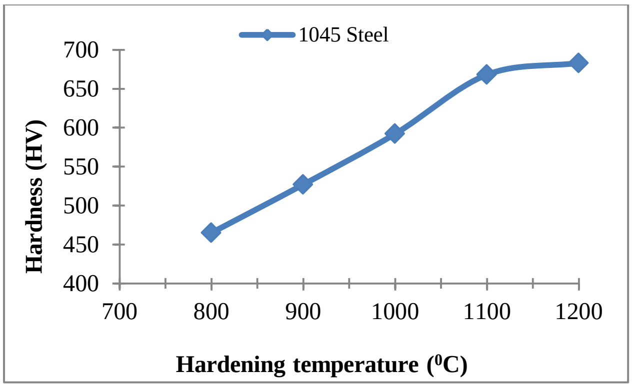

Fig.2 Graph of surface hardness as a function of hardening temperature

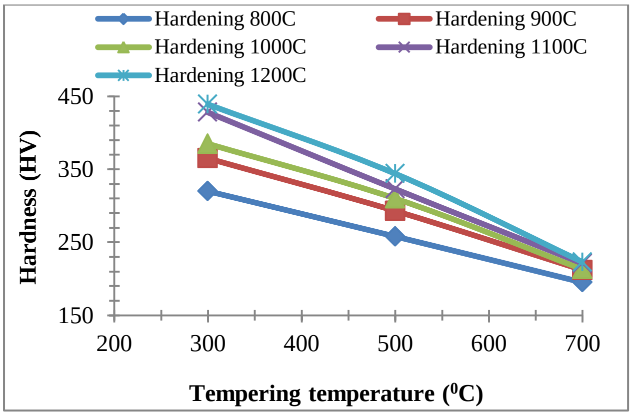

Fig.3 Graph of surface hardness as a function of tempering temperature

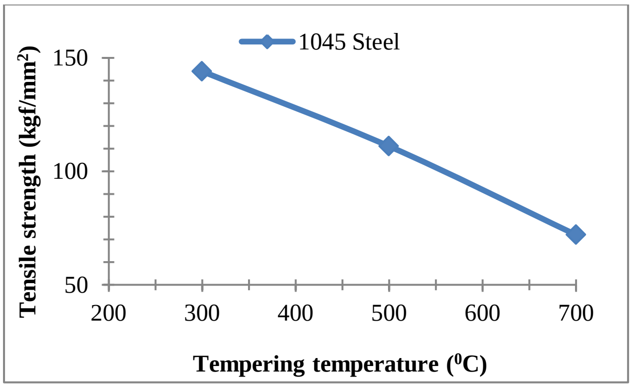

Fig.4 Graph of tensile strength as a function of tempering temperature following induction hardening at 1200^{o}C

For hardening temperatures of 800^{0}C to 1200^{0}C, the surface hardness increased consistently from 464 HV to 683 HV. It is likely that an increasing amount of martensitic structure formed as the hardening temperature was increased up to 1100^{0}C and for this temperature as well as 1200^{0}C a completely martensitic structure was obtained.

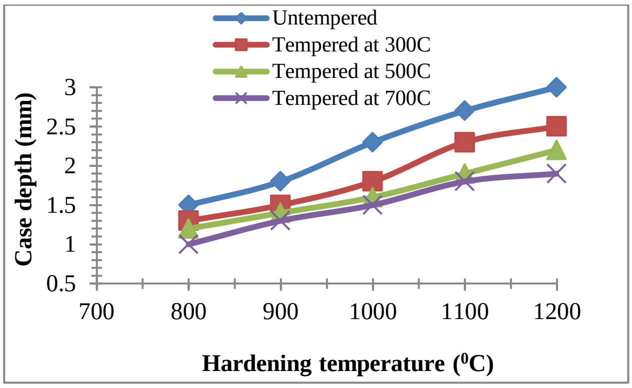

Fig.5 Graph of case depth as a function of hardening temperature

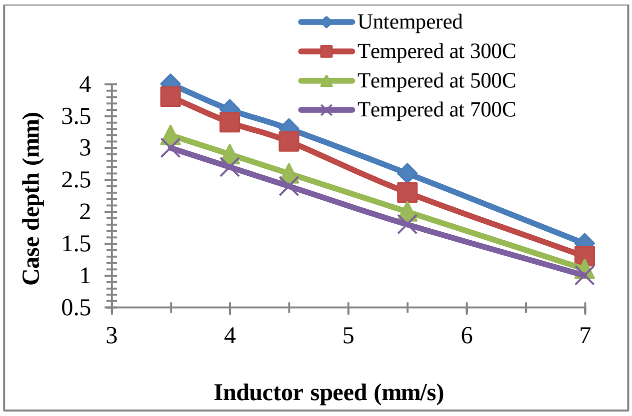

Fig.6 Graph of case depth versus inductor speed

When the induction heated and water quenched samples were tempered, the martensite structure decomposed to a carbide-ferrite mixture. The martensite progressively lost its tetragonality by precipitation of carbide from solid solution. The carbide forms as a series of transition phases, starting with epsilon carbide and then transforming eventually to cementite dispersed in a ferrite matrix (Qiu and Liu, 2012). As these structural transitions became more marked with increasing tempering temperature the surface hardness decreased, as shown by Fig. 3.

Fig. 5 shows that case depth was influenced by the hardening temperature. For treatment at 1200^{0}C, the hardened layer is much deeper than at the lowest hardening temperature, 800^{0}C. For tempered samples, the apparent thickness of the hardened layer decreased with increasing tempering temperature. However, quenching from a given temperature, say 1200^{0}C, should produce hardening to the same depth regardless of the subsequent tempering temperature (Jeng, *et al*, 1991). The apparent decrease shown in Fig. 5 is probably due to difficulty in defining the extent of the hardened layer as the overall hardness deceases towards the hardness of the as received steel. The speed of the inductor also affected the thickness of the hardened layer, Fig. 6, because at the high hardening temperature, the speed of the inductor was lower and eddy current heating extended more deeply into the rod sample. For these conditions, a fully austenitic structure is formed to a greater depth in the sample and therefore a thicker layer of martensite is formed on quenching (Kusmoko, *et al*, 2014). It is also likely that because the cooling rate decreases with depth, austenite transforms also to bainite or mixed bainite/martensite structures which, nevertheless, produce significant hardening.

As Fig. 4 shows, the tensile strength decreased with increased of tempering temperature. At a hardening temperature of 1200^0C and tempering temperature 300^0C, the tensile strength was 143.6 kgf/mm^2 (1400 MPa). For the same hardening temperature and a tempering temperature of 500^0C, the tensile strength was lower, 111.4 kgf/mm^2 (1092 MPa). Moreover, with the same hardening temperature and the higher tempering temperature of 700^0C, the tensile strength was much lower 72.3 kgf/mm^2 (708 MPa). The tensile strength before induction hardening was only 69 kgf/mm^2 (676 MPa). Therefore, tempering significantly lowered the strength of the hardened steel. However, tempering is necessary to reduce internal stresses and to produce a microstructure of ferrite and dispersed carbide which greatly increases the toughness (Kusmoko, 2000).

Summary and Recommendations

Induction hardening of 1045 steel at the highest temperature investigated (1200^0C), followed by water quenching, produced the highest hardness (685 HV), while lower hardnesses were obtained for the other temperatures (800^0C – 1100^0C). Water quenching produced high surface hardness due to the presence of the hard and brittle martensitic structure. Tempering caused the decomposition of the martensite into a ferrite-carbide mixture with higher toughness and lower hardness and strength. By means of induction hardening, 1045 steel can be processed to produce a hardened case or surface layer, while the core of the steel remains soft and tough. However, the case requires tempering to reduce the risk of cracking and spalling. This composite case hardened microstructure is suitable for crank shafts, gears and rail clips.

Additional mechanical testing, such as tensile, bending and wear testing, would be useful to more fully explore the mechanical properties of induction hardened 1045 steel. For applications involving precision equipment, such as gun components and gears, other properties such as dimensional stability and wear resistance are important for the longevity of the service life. Higher resolution microscopy such as SEM examination would also be useful in optimizing the structure and properties arising from the tempering treatment.

References

G. Krauss, (1977), Principles of Heat Treatment of Steel, ASM, Ohio.

Y. Lakthin, (1979), Engineering Physical Metallurgy and Heat Treatment, Mir Publisher, Moscow**.**

K. Thelning, (1974), Steel and Its Heat Treatment, Bofors Handbook, Butterworths, London.

A. Polar, (2009), Electromagnetic Detection and Monitoring of Creep Induced Damage in High Temperature Resistant Steels, PhD Thesis, The University of Illionis.

XW. Qiu, YP. Zhang, CG. Liu, (2012), Wear Resistance of Laser Cladding Ni-Based Alloy, *International Journal of Rare Metal Materials and Engineering*, vol. 41, pp. 182 - 185.

Ming-Chang. Jeng, Li-Yung. Yan, Ji-Liang. Doong (1991), Wear Behaviour of Cobalt-Based Alloys in Laser Surface Cladding, *International Journal of Surface and Coatings Technology*, vol. 48, pp. 225 – 231.

A. Kusmoko, D. Dunne, H. Li, D. Nolan (2014), Laser Cladding of Wear Resistant Stellite 6 Coating on P22 Steel Substrate with Two Different Energy Inputs, *International Journal of Advanced Materials Research*, vol. 911, pp. 97 - 101.

A. Kusmoko, (2000), Dry Sliding Wear Behaviour of Induction Hardened 4140 and Carburised 8617H Steels on 1040 Steel, MSc Thesis, The University of New South Wales.