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## A study surface layer and hardness produced by induction hardened S45C steel

### Abstract

A cylinder of Carbon Steel S45C with a ferrite and pearlite structure was analysed to improve the hardness and surface layer as well as the toughness. Accordingly, it is important to undertake a heat treatment process for the hardness and surface layer of this steel. The heat treatment process was carried out using induction heating with five different temperatures of 800°C, 900°C, 1000°C, 1100°C and 1200 °C followed by water quenching with certain cooling speed. The chemical compositions and microstructures of these samples were characterized by spectrometer and optical microscopy. The microhardness of the samples was measured and the surface treatment of the samples was examined using an induction heating furnace. The results showed significant case depth and surface hardness as well as microstructure with martensite and retained austenite that is hard and brittle because of internal stress. Further, to reduce the amount of retained austenite and internal stress, it is necessary to carry out tempering of 300°C, 500°C and 700°C in order to produce toughness of the steel with slightly reduce in hardness.

### Keywords

study, produced, induction, hardened, s45c, steel, layer, surface, hardness

### Disciplines

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## A Study Surface Layer and Hardness Produced by Induction Hardened S45C Steel

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**Keywords:** Induction hardening, S45C steel, Case depth and Surface hardness.

**Abstract.** A cylinder of Carbon Steel S45C with a ferrite and pearlite structure was analysed to improve the hardness and surface layer as well as the toughness. Accordingly, it is important to undertake a heat treatment process for the hardness and surface layer of this steel. The heat treatment process was carried out using induction heating with five different temperatures of 800°C, 900°C, 1000°C, 1100°C and 1200 °C followed by water quenching with certain cooling speed. The chemical compositions and microstructures of these samples were characterized by spectrometer and optical microscopy. The microhardness of the samples was measured and the surface treatment of the samples was examined using an induction heating furnace. The results showed significant case depth and surface hardness as well as microstructure with martensite and retained austenite that is hard and brittle because of internal stress. Further, to reduce the amount of retained austenite and internal stress, it is necessary to carry out tempering of 300°C, 500°C and 700°C in order to produce toughness of the steel with slightly reduce in hardness.

### Introduction

S45C is a soft carbon steel material with the initial hardness of 183 HV, that is used for hardfacing of various component parts for applications requiring surface treatment and wear resistance. The microstructure of S45C contains ferrite and pearlite. S45C has hardenability to be heat treated then tempered to produce a steel which is hard and tough [1].

Materials for rail clips and gear applications, such as S45C, must have good wear resistance. In order to have good wear resistance, the steel has to have a high hardness. Therefore, a surface treatment, such as induction hardening is very important process for achieving a suitable surface hardness for wear resistance applications [2]. The S45C steel has not been extensively studied for the development on wear resistance by using induction hardening especially followed by tempering with different temperatures to produce toughness of final products.

The heat treatment process is a process where a steel is heated and held above the critical temperature to produce an austenitic structure. Then followed by fast cooling rate with water or oil and also can be by air cooling for a slower rate. The martensite structure produced by fast cooling is hard and brittle, thus technically is not a good outcome for final product due to present of cracks. Therefore, a tempering process needs to be carried out after hardening process. Tempering is where a steel is heated and held under the critical temperature to remove the internal stress after cooling and improve the toughness with reduce in hardness and strength [3].

The induction hardening mechanism is based on induced current flow in the steel conductor, due to magnetic current surroundings it. If the conductor contents magnetic current is produced by a high frequency current, then Eddy currents near the steel surface are important, and quickly increase the temperature to the austenitising range from quenched to obtain martensite structure in the surface layer of the steel [4].

The purpose of this study was to evaluate the surface hardness and case depth of S45C steel material produced by induction hardening followed with tempering for gear applications, tools and rails clips.

### Experimental Methods

**Induction hardening.** The induction hardened of S45C steel was carried out at heat treatment department of Army industry (steel industry) in Bandung, Indonesia. The heat treatment was conducted on induction furnace with hardening temperatures of 800<sup>0</sup>C, 900<sup>0</sup>C, 1000<sup>0</sup>C, 1100<sup>0</sup>C, 1200<sup>0</sup>C and the heating time of 2s for each temperature, followed by water quenching for 55s. The details of induction hardened 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 initial sample as received was cylinder with 30 mm diameter and 120 mm length.

**Tempering.** After hardening process followed by water quenched, the tempering was carried out at temperature of 300<sup>0</sup>C, 500<sup>0</sup>C and 700<sup>0</sup>C for 30 minutes each tempering in the tempering oven, followed by air cooling.

**Characterisation of S45 Steels.** The initial hardness measurement for the raw material was conducted using Brinell hardness testing machine with a load of 750000 g. Then the microhardness measurements were made at intervals of 0.50 mm through the surface layer of induction hardened S45C steel using a Vickers hardness testing machine with a load of 5000 g. The cross-section steel samples were then polished and etched in a 2% nital solution to reveal the microstructures using an optical microscope.

### Results

**Nominal Compositions.** The compositions of S45C steel was determined by Spectrometer, Table 1. Table 1 shows the nominal compositions of the S45C steel.

Table 1. Nominal compositions (wt%) of the S45C steel

(%)	Co	Cr	Fe	W	Ni	C	Mn
S45C	0.0569	0.0456	98.3012	0.000	0.0454	0.4381	0.7723
(%)	P	S	Mo	V	Cu	Si	
S45C	0.0032	0.000	0.0092	0.000	0.0676	0.2605	

**Optical Microscopy of S45C Steels.** The microstructure on the S45C steel substrate had a ferrite-pearlite appearance, while the surface layer produced a martensitic structure. Figs. 1(a-d) show the microstructures evolution for hardening with non temper, Fig. 1(a), with tempering 300<sup>0</sup>C, Fig. 1(b), with tempering 500<sup>0</sup>C, Fig. 1(c) and with tempering 700<sup>0</sup>C, Fig. 1(d). It can be seen in Fig. 1(a) that an acicular structure that is due to the formation of martensite with lath morphologies. If the tempering temperature increased, the acicular structure becomes less visible as the martensite continuously decomposes to a ferrite and carbide mixture, Fig. 1(b-d).

**Microhardness Testing of Surface Layer S45C Steel.** The microhardness of the surface layer of S45C for hardening temperature 1200<sup>0</sup>C, the surface layer hardness was about 683 HV, it is consistent with untempered martensite in steel with 0.43%C. In comparison, 464 HV was examined for hardening temperature 800<sup>0</sup>C. In this hardening temperature did not produce a fully austenitic structure. While the microhardness of the surface layer of S45C after tempering at 300<sup>0</sup>C was about 439 HV for a hardening temperature 1200<sup>0</sup>C compared with 344 HV after tempering at 500<sup>0</sup>C and 223 HV after tempering at 700<sup>0</sup>C. The hardness of the unaffected substrate was about 183 HV.

**Hardening and Tempering temperatures.** Fig. 2, shows that the surface hardness increased sharply with increasing hardening temperature. The effect of tempering is shown in Fig. 3, the surface hardness decreased with increasing tempering temperature. .

**Case Depth.** Table 2 shows that the case depth increased with hardening temperature. It can be seen that the case depth deeper as the hardening temperature increased. Table 3 shows the case depth is influenced by the speed of inductor. The case depth was shallower as the inductor speed increased.

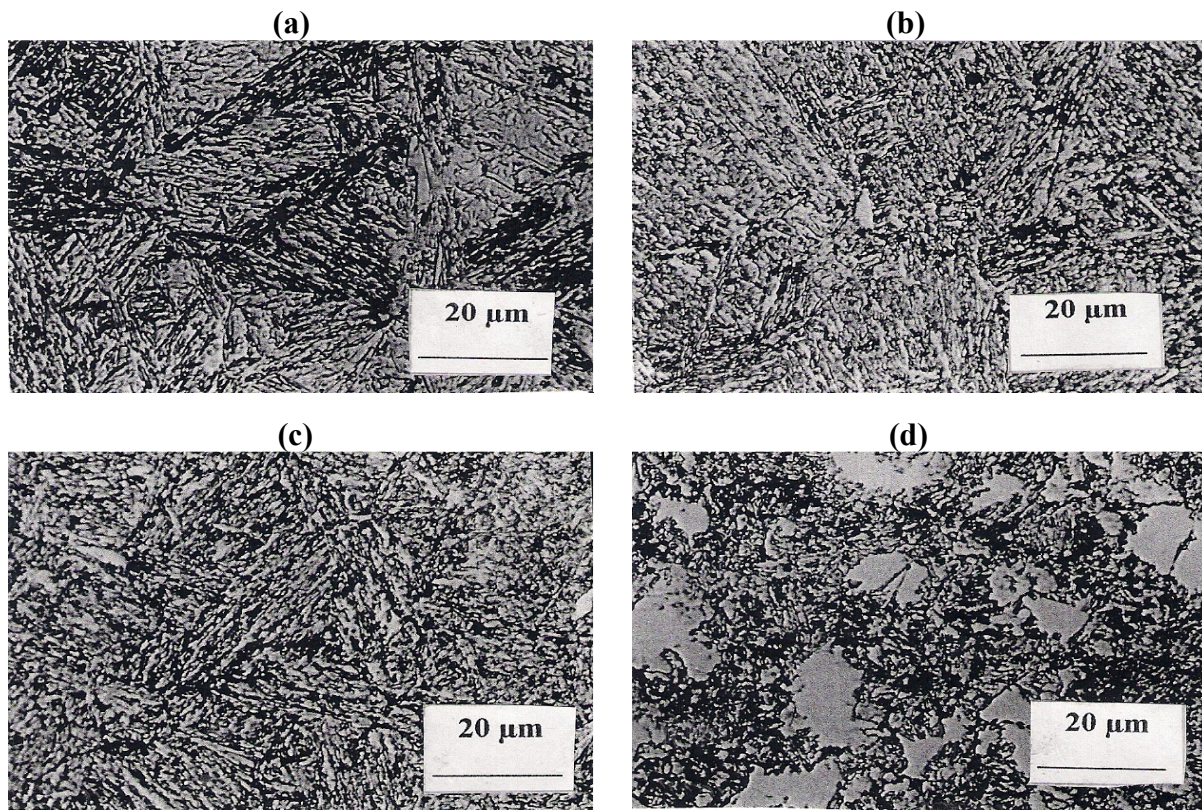


Figure 1. Optical micrographs of samples of S45C steel subjected to a hardening temperature of  $1100^{\circ}\text{C}$  and water quenched (a) Non-tempered, (b) tempered at  $300^{\circ}\text{C}$ , (c) tempered at  $500^{\circ}\text{C}$  and (d) tempered at  $700^{\circ}\text{C}$ .

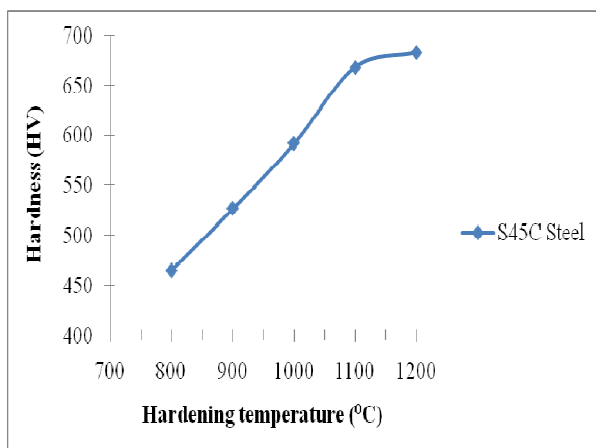


Figure 2. Graph of surface hardness as a function of hardening temperature.

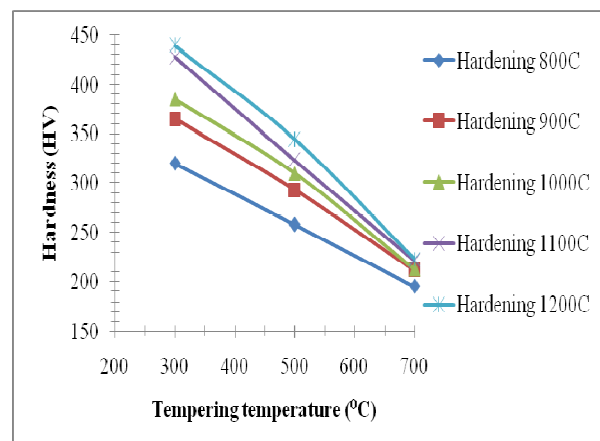


Figure 3. Graph of surface hardness as a function of tempering temperature.



Table 2. Case depth for hardening after non-tempered and tempered at the temperatures indicated

Hardening (°C)	Case depth (mm)			
	Non-Tempered	Tempered at 300°C	Tempered at 500°C	Tempered at 700°C
800	1.5	1.3	1.2	1
900	1.8	1.5	1.4	1.3
1000	2.3	1.8	1.6	1.5
1100	2.7	2.3	1.9	1.8
1200	3	2.5	2.2	1.9

Table 3. Case depth for inductor speed after non-tempered and tempered at the temperatures indicated

Speed (mm/s)	Case depth (mm)			
	Non-Tempered	Tempered at 300°C	Tempered at 500°C	Tempered at 700°C
3.5	4	3.8	3.2	3
4	3.6	3.4	2.9	2.7
4.5	3.3	3.1	2.6	2.4
5.5	2.6	2.3	2	1.8
7	1.5	1.3	1.1	1

## Discussion

The results from the tests conducted for induction hardened of S45C steel showed that a lower hardening temperature resulted incomplete martensite formation and a lower surface hardness. A full martensitic structure was obtained for the tests conducted at 1100°C, as shown in Fig. 1(a).

For hardening temperature at 800°C to 1200°C, the surface hardness increased consistently from 464 HV to 683 HV. It is likely that an increasing number of martensitic formed as the hardening temperature increased until 1100°C as well as 1200°C, a martensitic structure was fully obtained.

When the S45C steel samples were induction hardened and water quenched then continued with tempering process, the martensite structure decomposed to a carbide-ferrite mixture. The martensite continuously lost the tetragonality by precipitation of carbide from solid solution. The carbide forms as a series of transition phases, starting with epsilon carbide and then finally transforming to cementite in a ferrite matrix [5]. As these structural transitions became more indicated with increasing tempering temperature the surface hardness decreased, as shown in Fig. 3. However, tempering is necessary to reduce internal stresses and eliminate the cracks occurred as well as to produce a microstructure of ferrite and carbide which significantly increases the toughness.

Table 2 shows that case depth was influenced by the hardening temperature. At hardening 1200°C, the thickness layer produced is much deeper than at the lowest hardening temperature, 800°C. In contrast, the tempered samples, the apparent thickness of the hardened layer decreased with increasing tempering temperature. However, quenching from a given temperature, such as 1200°C, should result hardening to the same depth whatever of the subsequent tempering temperature [6]. It is probably due to the difficulty in defining the extent of the hardened layer as the overall hardness decreases towards the hardness of the initial steel sample. The speed of the inductor also influenced the thickness of the hardened layer, Table 3, because at the high hardening temperature, the speed of inductor was lower and eddy current heating extended more deeply into the cylinder sample. For these conditions, a fully austenitic structure is produced to a bigger depth in the sample and thus a thicker layer of martensite is produced on quenching [7]. It is likely that because the cooling rate decreases with depth, austenite transforms also to bainite or mixed bainite/martensite structures which produce significant hardening [8].

### Summary and Future works

Induction hardened of S45C steel on temperature 1200<sup>0</sup>C with water quenched has produced highest hardness (685 HV) compared with other temperatures (800<sup>0</sup>C – 1100<sup>0</sup>C). Water quenching produced high surface hardness due to the presence of the hard and brittle martensitic structure. Tempering resulted the decomposition of the martensite into a ferrite-carbide mixture with higher toughness and lower hardness. By using of induction hardening, the S45C steel is able to produce a hardened layer or surface layer, while the core of steel remains soft and tough. However, the case requires tempering to reduce the risk of cracking. This case hardened microstructure is suitable for crank shafts, gears and rail clips.

It is recommended to undertake other mechanical testing, such as tensile test, bending test and wear testing. In the applications for precision equipment, such as rail clips, gun components and gears, S45C steel is required to have toughness. Therefore, quenching with water is recommended and if this method is selected, it must be tempered several times to produce better toughness. SEM examination is recommended to analyse the structures, interface and possibility of cracks present. Tensile strength measurements after tempering is significant to ensure the toughness of the S45C steel for service, it will be discussed further in another paper.

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## **A Study Surface Layer and Hardness Produced by Induction Hardened S45C Steel**

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