CSN 12050 Carbon Steel Mechanical Property Enhancement Using Thermal Treatment to Optimize Product Sustainability

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Abstract. Many of the mechanical properties of steel can be improved under controlled sequence of heating and cooling to modify their properties and to meet the desired engineering applications. In this study, the effect of heat treatment cycles (hardening, normalizing, annealing, tempering and recrystallization) on the mechanical properties of CSN 12050 carbon steel have been studied. The aim of the study of this paper is to enhance the ease of machinability for CSN 12050 carbon steel products and to achieve the ultimate goal of product sustainability optimization. The treated and untreated samples change in properties is examined using standard methods. Spectro test TXC25 machine model number 2010, Vickers Hardness tester (HV), and WP310 universal material tester is used to analyze chemical composition and mechanical properties of the specimens respectively. The standard mathematical equations are used to calculate the experimental results of mean values for the test samples of HV and the stress-strain values obtained from the tensile test; later converted to true stress-strain values. Results showed that the mechanical properties of CSN 12050 carbon steel can be changed and improved through annealing and recrystallization process for the ease of machinability. Moreover, the enhanced mechanical properties of CSN 12050 carbon steel can be enlighten the goal of product sustainability through the achieved ease of machinability in dry turning condition.

Keywords: Mechanical-properties · Heat-treatment · Machinability · Product-sustainability

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1 Introduction

Manufacturing engineers are often challenged to find ways to improve machinability without harming material performance, which are much focused on the machining efficiency and productivity. However, unlike most material properties machinability cannot be simplified into exclusive work material property. It is a subsequent property of the machining system which is mainly affected by cutting tool materials, and work materials properties etc.

Engineering materials could be developed with improved machinability or more uniform machinability through chemical component adjustment, modification of microstructure, and mechanical properties enhancement. Hence, to achieve the improved work material for better machinability the most important and appropriate properties enhancing operations are heat treatment. To investigate the effect of heat treatment in-relation to the mechanical properties (tensile and hardness), CSN 12050 carbon steel is the best candidate. This steel is widely used for industrial applications like Shafts, Gears, Bolts, Pins, connecting rods, Rams, Axles, Crankshafts, Studs, Rams, Guide rods, Spindles and Hydraulic clamps etc. Among these products the Pin product which is used for cane carrier chains of Sugar Mills is selected to optimize the machinability. It is predominantly manufactured at Hibret Manufacturing and Machine Building Industry (HMMBI) of Ethiopia. The motive to investigate the CSN 12050 carbon steel is initiated from the outcome of preliminary case study at HMMBI Ethiopia and the problem identified thorough onsite observation of the manufactured product quality and defects.

The CSN 12050 carbon steel is usually recommended by the suppliers to carry out heat treatment after initial stock removal to achieve better mechanical properties. "Many of the important mechanical properties of steel, including yield strength and hardness, the ductile-brittle transition temperature and susceptibility to environmental embrittlement can be improved considerably by refining the grain size", [1, 2]. The mechanical properties of steel are strongly connected to their microstructure obtained after heat treatments which are performed to achieve good hardened and tensile strength with sufficient ductility [3, 4].

Different types of steels are heat treated in manufacturing industries and represent a major demand for property enhancement [5, 6]. There is an abundant amount of research work done on the heat treatment process and different steel materials properties [7], but sustainability issues of heat treatment processes have rarely been given much attention. So far, there is hardly any reported work focus on heat treatment process of CSN 12050 carbon steel to optimize its mechanical properties for machinability in the aspect of product sustainability. Therefore, in this research effect of heat treatment process on CSN 12050 carbon steel product sustainability issues that relate to machinability is presented. Due to time, budget and others constraints among many properties of CSN 12050 carbon steel, in this research chemical component adjustment, and mechanical properties (hardness and tensile) test is conducted.

1.1 Materials and Methods

The selected candidate material used for the test in this investigation is CSN 12050 carbon steel rolling bar. To examine the effect of thermal treatment on the CSN 12050 carbon steel, the experimentation is carried out in relation to; examine the chemical composition, sample preparation and investigation of mechanical properties of CSN 12050 carbon steel material.

1.2 Aim and Objective of the Study

The aim of the study is to enhance the performance of machinability for CSN 12050 carbon steel products and to achieve the ultimate goal of product sustainability optimization.

1.3 The Objectives of Research

To understand and analyze the alloying elements, improve tensile strength, ductility and hardness. Accordingly, to eliminate the need of cutting fluids or reduce the cost needed for the cutting fluids and reduce the power consumption during machining the CSN 12050 carbon steel.

2 Material Chemical Composition

The experimental investigation of the study taking place by identifying CSN 12050 carbon steel chemical composition analysis of Spectro test TXC25 machine as shown in Fig. 1 (Table 1).

Fig. 1. Spectro test TXC25 machine set up for sample calibrations for CSN 12050 carbon steel experimentation.

Table 1. CSN 12050 carbon steel chemical composition analysis of Spectro test TXC25 machine.

CSN 12050 carbon steel mechanical composition weight by percent										
C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	Fe
0.47	0.24	0.59	0.045	0.085	0.074	0.003	0.017	0.016	0.079	98.4

3 Thermal Treatment of CSN 12050 Carbon Steel and Sample Preparation

Heat treated CSN 12050 carbon steel can possesses good homogenous metallurgical structures, giving consistent machining properties to achieve the goal of product sustainability optimization. The mechanism of heat treatment mainly categorized into thermochemical, thermal treatment and thermo mechanical processes. Thermochemical process which consist of boronising, carburizing, and nitriding. Thermal treatment consists softening (annealing and normalizing) and hardening (hardening and tempering) processes. Thermo mechanical processes which consist of mechanical working operation through the heat-treatment operation like hot forging, rolling etc. The experimentation of this study is conducted on the thermal treatment (hardening, normalizing, annealing, tempering and recrystallization) processes. Samples used for standard cylindrical specimens (12 mm outside diameter/gripping head, 5 mm inside diameter/gauge length, 32.5 mm minimum gripping length and 55 mm gauge length) is prepared by turning using CNC lathe machine.

4 Mechanical Property Experimental Examination of CSN 12050 Carbon Steel

Determination of mechanical properties of materials is more complicated due to the role of different mechanisms. The treated and untreated samples shown in Fig. 5 are used to determine the mechanical properties. The mean value of hardness number experimental results is determined by taking five hardness readings at different orientations on the samples using Vickers Hardness tester (HV). The Vickers hardness tester uses a square-based pyramid diamond indenter with an angle of 136^0 between the opposite faces at the vertex, which is pressed into the surface of the test piece using a prescribed force (F). Measuring ranges from 5–2900 HV and test force 9.807, 49.03, 98.07, 196.1, 294.2, and 490.3 N (1, 5, 10, 20, 30, and 50 kgf). The mean values for the test samples of HV experimental result reports are expressed as:

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n} \tag{1}$$

Where, $\overline{X}$, the mean of X_i, n, the number of data point, and X_i, each of the value of data point.

For tensile properties a cylindrically turned tensile specimens are loaded into a WP310 universal material tester 50 kN (Table 2).

Table 2. Thermal treatment conditions to investigate the mechanical properties test.

Conditions	Temperature (°C)	Handling time (min)	Cooling medium
Hardened	850	40	Water
Normalized	850	40	Air
Annealed	850	40	Furnace
Tempered	540	40	Air
Recrystallized	550	60	Air

The testing machines Vickers Hardness tester, WP310 universal material tester 50 KN and finished/tested sample of specimens are shown in Figs. 2, 3, 4, and 5 respectively.

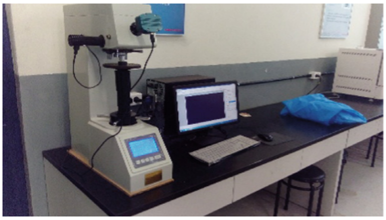


Fig. 2. Vickers Hardness tester

Fig. 3. WP310 universal material tester 50 kN

Fig. 4. Starting point for tensile testing

Fig. 5. Tested specimens at fracture point

The general mathematical equations used to compute the experimental result expressed as:

$$HV = \frac{0.102 \times 2F\left(\sin\frac{136^0}{2}\right)}{d^2} \quad (2)$$

Where, HV, Hardness measured value and F, test force and d, is diagonal of square-based pyramid diamond indenter.

The WP310 universal material tester 50 kN recorded the force elongation, stress elongation, and tensile strength for all the specimens which is used for further analysis.

The stress–strain values obtained from the tensile test gives the engineering stress–train values which is based on the original cross-sectional area of the test specimens. These values are later converted to true stress–strain values which is more important in manufacturing. The basic equations used to evaluate the engineering/true stress and engineering/true strain derived from [8]. The engineering stress (σ_E) at any point on the curve is defined as the force divided by the original area (A_0), and the equations for engineering strain, % elongation, % area reduction, true stress and true strain are respectively expressed as:

$$\sigma_E = \frac{F}{A_o} \quad (3)$$

$$\varepsilon_E = \frac{L - L_o}{L_o} \quad (4)$$

$$\%EL = \frac{L_f - L_o}{L_o} \quad (5)$$

$$\%RA = \frac{A_o - A_f}{A_o} \quad (6)$$

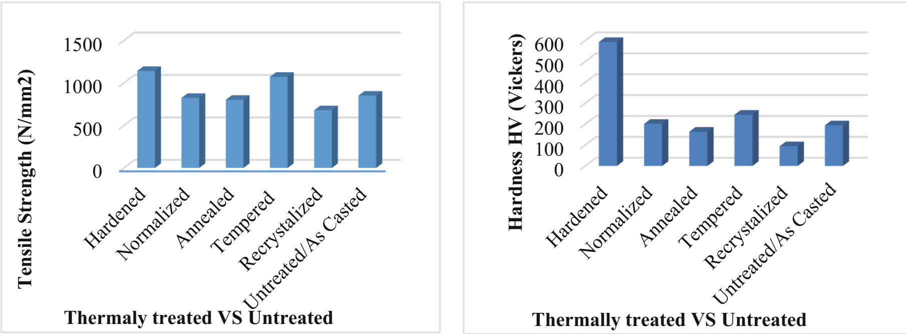
$$\sigma_T = \frac{F}{A_o}(1 + \varepsilon_E) = \sigma(1 + \varepsilon_E) \quad (7)$$

$$\varepsilon_T = \ln(1 + \varepsilon_E) \quad (8)$$

5 Results and Discussion

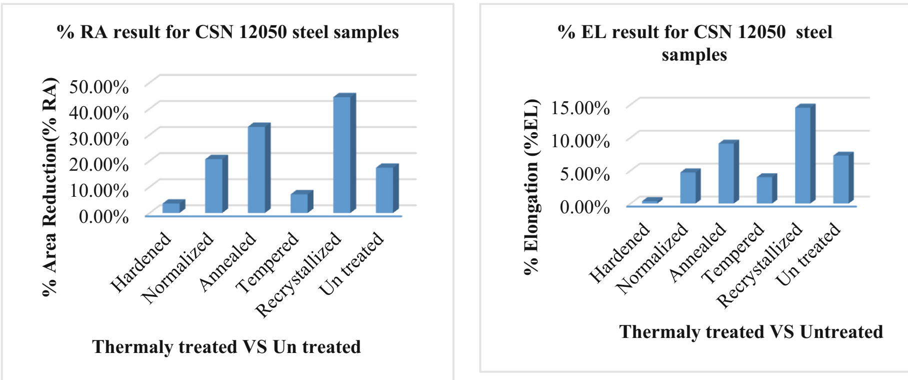
The WP310 universal material tester which is calibrated in unit of 50 kN were subjected to test the heat-treated specimens. The thermal treatment effects of hardened, normalized, annealed, tempered and recrystallized specimens are examined in-relation to their mechanical properties (hardness, tensile strength, percentage elongation, and percentage reduction) [5, 6].

The variability in tensile strength, percentage elongation, percentage reduction, hardness, true stress and true strain of heat treated and untreated CSN 12050 carbon steel are shown in Figs. 6, 7 and 8, respectively.



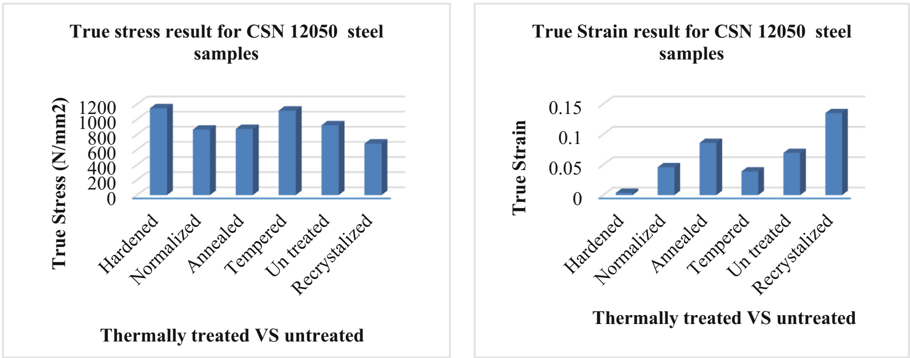
(A) (B)

Fig. 6. (A) Tensile strength and (B) hardness test result for treated and untreated CSN 12050 carbon steel samples



(A) (B)

Fig. 7. (A) % of Area Reduction (% RA) and (B) % of Elongation test result for thermally treated and untreated CSN 12050 carbon steel samples



(A) (B)

Fig. 8. (A) True stress test and (B) true strain result for thermally treated and untreated CSN 12050 carbon steel samples

6 Conclusions

This study set out to investigate thermal treatment of CSN 12050 carbon steel to optimize machinability some of the key findings are as follows:

- This study has shown that different thermal treatment of CSN 12050 carbon steel gave diverse experimental result of mechanical properties. The optimization of machinability depends on the mechanical properties of the CSN 12050 carbon steel test result. For instance, tensile strength, and hardness of CSN 12050 carbon steel increased with resistance to plastic deformation, while decreased its ductility (% elongation, % area reduction) due to the influence of strain hardening.
- In terms of machinability of CSN 12050 carbon steel, the experimental result of hardened, tempered, and normalized test samples showed that with increased tensile strength and hardness respectively. The hardness and tensile strength can be an indicator of machinability but, too much hardness affect the quality of machining and the ease of machinability. As a result, the hardened, tempered and normalized test samples showed that with increased tensile strength and hardness value than untreated test sample.
- On the contrary, the experimental result of annealed and recrystallized test samples showed that with decreased tensile strength and hardness, and increased ductility (% elongation, % reduction) respectively. These results showed that the improvement of the tensile strength and hardness of the CSN 12050 carbon steel for better quality of machining and high productivity. Moreover, it is possible to machine in dry condition and reduce the cost of cutting fluids.

  Finally; from the above thermally treated mechanical properties investigation result of CSN 12050 carbon steel samples recrystallization is selected for product sustainability optimization:

  By heating the CSN 12050 carbon steel to the recrystallization temperature before deformation, the amount of straining can endure substantially, as a result it can be predicted the forces and power required to carry out the process significantly reduced. Which means through the reduction of cutting forces and power requirement during machining the product can be manufactured with minimized cost, reduced carbon emissions along with safe personal health. Also, by heating to the recrystallized temperature the machining process can be carried out in dry condition to reduce the cost needed for cutting fluids, the associated environmental and personal health risks.

- If the CSN 12050 carbon steel is heated to sufficiently elevated temperature and then deformed, strain hardening does not occur. Instead, new grains are formed that are free of strain, and the CSN 12050 carbon steel behaves as a perfectly plastic material; that is, with a strain-hardening exponent $n = 0$.
- Recrystallization is a temperature dependent characteristic of metals that can be exploited in manufacturing industries. Hence, in this study among the test sample of thermally treated CSN 12050 carbon steel recrystallized sample test result highly enhanced for successful machinability to achieve the triple bottom line goal of sustainability (environmentally, economically, and societally) sound full. This is a good opportunity for HMMB METEC Ethiopia to optimize machinability and manufacture sustainable pin product for their customer's satisfaction with other surplus benefits.

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