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Sustainability of Metal Scrap Return toward Product Characteristic of Agriculture Utensil from Manufacturing Process Model by Forging and Quenching

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ABSTRACT

Hot forging is a heat treatment process by heating metal in heat furnace until upper crystallization temperature and it gives external forces up to deformation's goal meet. The objective of this research is to compare and analyze scrap return following hot forging process in terms of hardness characteristic, tensile strength, and micro-structure. The cooling media types used in this study was SAE 20, SAE 40, SAE 50, SAE 90. This study successfully obtained hardening capability, optimum tensile strength and micro-structure scrap returns after hot forging and continued by quenching with the cooling media. Research methods in this study include: (a) test sample manufacture, (b) data retrieval namely chemical composition test, hardness test, tensile test and micro-structure observation. Research result shown that the highest value of hardness characteristic and tensile strength obtained from quenching type by SAE 20 with hardness rate of 53.5 HRC and tensile strength 65 kg/mm2 with dominant perlite phase compare to ferrite phase. Meanwhile, quenching process with SAE 90 resulted in hardness type of 49.6 HRC with tensile strength 53 kg/mm2, α phase more dominant compared to pearlite phase. This study concludes that scrap returns metal after hot forging and quenching with cooling media SAE 20, SAE 40, SAE 50 and SAE 90 hardness characteristic and its tensile strength tends to fall and phase which formed ferrite phase more dominant compared pearlite phase.

Keywords : Hot Forging, Quenching, Hardness Number, Tensile Strength, Microstructures, Recycle Material, Sustainable Material.

I. INTRODUCTION

Metal materials, usually refer as metal scrap returns, which is metal material that experience failure or fracture caused by several factors such as use of frequent loading that cause fatigue, wear due to friction, defect due to casting process or machining process, crack due to welding process. As the consequence, construction or component failure will degrade the performance or efficiency.

In producing hoe for agriculture tool, blacksmith needs metal scrap returns which consist of low-carbonate steel and high-carbonate steel with different hardness properties. Production process of the hoe is started by heating scrap returns in heat furnace until reaching 935 ^{0}C using wood charcoal. Following the heating process, scrap returns is treated by hot forging process for several times or manual hot forging process until forming hoe product, then continue with water cooling process. In several cases, hoe may lose its function due to several factors, including (a) hardness rate below Indonesia National Standard, (b) water cooling cause marten site with hard and brittle properties, and (c) manual forging process. In order to increase tool's quality, technology innovation is needed by increasing the temperature of wood charcoal heating inside heat furnace above the temperature of recrystallization (935 ^{0} C), by changing cooling process using SAE 20, SAE 40, SAE 50, SAE 90 oil to produce ferrite and pearlite structure, or by applying hydraulic heat forging.

Metal scrap returns material is a material that cannot be destroyed because its corrosive property contaminates the environment. To overcome this problem, recycling it in several ways is needed including re-melting and forming process to produce beneficial products for human needs, especially for agricultural tools. One of the ways to produce agricultural tools is wrought model of heating (hot forging) and continues with rapid cooling process (quenching) at the end of the process.

Figure 1. Metal Scrap Return

This research aims to find out technology innovations to increase the hardness quality of hoe by implementing several processes namely: (a) heating metal scrap returns in heat furnace at above recrystallization temperature (935 ^{0} C), (b) implementing hydraulic forging on scrap returns following heating process, (c) cooling process for metal scrap returns following heating process using SAE 20, SAE 40, SAE 50, SAE 90 oils. This research also aims at discovering hoe quality by several tests including hardness test, tensile strength test, and microstructure observation.

This study focuses on the use of waste material including metal scrap returns, lubricating oils: SAE 20, SAE 40, SAE 50, SAE 90, and charcoal wood fuel to produce a specific agriculture tool product that is hoe. Procurement of metal scrap returns of metal scrap returns materials can be obtained easily for the blacksmiths in the machining industry, welding industry, foundry industry, automotive and motorcycle workshops. However, this study is limited on the usage of the above materials to produce hoe, despite there are several other agriculture tools such as sickle, trowel, and shovel.

II. LITERATURE REVIEW

Forging process is a metal forming process to generate products especially for agricultural tools (Figure 2) by providing external force with specific loading rate. The process of forging work piece is strucked with tools through several stages with a certain loading rate and forging process can be done in two ways: hot forging and cold forging [1]. (Hosford, 1983).

Figure 2. Agricultural Tools

Hot forging can be done manually by hammering or by using loading rate of hydraulic system on the substance (anvil). Work piece results have wrought fibre structure or a flow line in the direction of the desired strength properties, and these properties, related to the nature of violence. Hot forging flow lines result tends to follow the pattern of the outer shape of the work piece which to be forged.

Forging process used in metal industry to make products that are not uniform, ranging from the shape and size of small to large. The forging process is generally performed at high temperatures or refers as hot working for large workpiece manufacturer, while for small workpiece forging process is conducted at low temperature or refer as cold working, [1]. Hot working is a metal forming process by heating the work piece above the recrystallization temperature and subsequently giving external force to change the desired shape. Cold working is a metal forming process plastically below recrystallization temperature and generally carried out at room temperature without heating the workpiece. To perform hot forging, metal is heated inside furnace using wood charcoal at above recrystallization temperature from 500 ^{0} C to 700 ^{0} C (Figure 2), followed by quenching process using several media such as water, oil, Al_2O_3, brine, or ice.

Research on the effect of hydraulic steel forging process on hardness property by [2] concluded that manual flame hardening treatment is able to increase the hardness of hydraulic steel forging product, making this process applicable for producing cutting tools in blacksmith industry. On the other hand, annealing treatment, forging and manual flame hardening result in highest temperature of 866 HV and martensite and ferrite microstructures. Research by [3] conducted a study on increasing product hardness of hoe by carburizing process using albasia (albizzia falcata) wood charcoal and quick quenching. The study concluded that pack carburizing method is able to increase hardness value, indicated by increase in carbonate percentage in hoe material. Hoe hardness value as the result of this study has met standard value of Indonesian National Standard 02-0331-1989 KW III with the score of 39 HR_C. Another related study on forging process of piston material conducted by [4] concluded that forge piston delivers higher hardness temperature for 14.9% of 121.1 HV compare to cast piston. However, forge piston experienced deformation which caused strain hardening. [5] studied that dual phase heating treatment consequently increases pull and hardness properties with maximum rate of 770 C/90' from the initial condition σu =611.98 N/mm^2, σy = 343.75 N/mm and hardness of 16.67HR_C increased to σu = 846.35 N/mm^2, σy = 570,31 N/mm^2 and hardness of 38 HR_C, but elongation is proven to be decreased from 32,29% to 22,98%. Tempering on mechanical property resulted in maximum rate of σu = 760.42 N/mm^2 and hardness of 33 HR_C on dual phase 770 C/90' on temper 450 C/30', and maximum rate of elongation for 38.54% is gained from dual phase 770 C/60' on temper 600 C/30'.

Figure 3. Heat Furnace in the Study

III. RESEARCH METHODOLOGY

A. Research Stages

This research is the continuation study on metal scrap returns utilization for production of hoe as agricultural tool with high quality. There are several research steps conducted in this study, including (a) preparation of metal scrap returns, (b) furnace heat using wood coal until reaching the temperature 935 ^{0}C, (c) hot forging, (d) quenching process with oil variations, (e) test, and (f) analysis. The chart (Figure 3) displays the research stages from the beginning step of preparation until the summarization of the research result.

This study uses two kinds of material namely outer and inner material. Outer material consists of steel with moderate carbon level which have hard and ductile properties, while inner material includes high-carbon steel with hard and brittle properties. Both materials were heated in furnace until reaching the temperature of 935 ^{0}C using wood coal. Following the heating process, the materials were processed to form hoe product using hammer as forming tool. Once the product is formed, quenching process is conducted to change the properties and microstructure of the materials, using oil variance of SAE 20 and SAE 90. Some tests were conducted to gain several rates in the material, including hardness test to gain hardness rate, tensile test to prove the tensile rate, and micro-structure observation to describe grain boundaries and phase type.

B. Research Equipment

Following heating and hot forging process, some properties of hoe product should be measured in terms of hardness, tensile strength, and microstructure. The tests required specimen which were constructed using the following equipment: (a) machinery, namely: Furnace, Blower, Quan meter, Rockwell Hardness Number, Universal Testing Machine, Microscope Metal, Pre-grinder, Polishing, Mounting Press, Film Processing Apparatus, and Machine Cutting Tool, and (b) other supporting equipment, namely: Calipers, Digital Thermocouple, Hammer, Anvil, Cooling Container, Forceps and Rub the Paper grade #300 up to #1000.

C. Testing Variables

In accordance with purpose of the research which aims to increase the hardness quality of hoe by technology innovation, some transformation processes were conducted, including: (a) metal scrap returns heating in furnace, (b) hot forging, and (c) quenching. To support the above processes, testing variables were determined beforehand, as described in Table 1.

TABLE 1
TESTING VARIABLES

No	Testing Variables	Description
1	Specimen	Metal scrap returns type of low carbon steel and high carbon steel
2	Quenching	Lubricating oils consists of SAE 20, SAE 40,SAE 50, SAE 90
3	External Force	5 kg (for forging process)
4	Furnace temperature	935 ^{0} C
5	Temperatures	800 ^{0} C
6	Etching Solution	HNO_3 2 % and 98 % alcohol
7	Furan resin	½ liter
8	Solid Fuel	Teak wood charcoal

IV. RESULTS AND DISCUSSION

A. Results

Hot forging is a metal forming process by heating the metal scrap returns consisting of outer material and the material in the kitchen heating up above the temperature of recrystallization (A_1) 935 ^{0}C using heat energy. From the hot forging then loading of 5 kgs is performed loading as an external force gradually and continued quenching with oil media: SAE 20, SAE 40, SAE 50, SAE 90 to a temperature of 800 ^{0} C. The result of the chemical composition of metal scrap returns are used for hot forging consists of material beyond 0.132% carbon (C) including a group of low-carbon steel which has the properties of soft, malleable, and low hardness but high tenacity. The material in 1.261% C includes a group of high-carbon steel which has high hardness properties but low toughness (Table 1). Meanwhile, other elements that are impurities are in low-carbon steel such as: 0.007% phosphorus (P), 0.005% sulphur (S), 0.033% aluminium (Al), 0.011% chromium (Cr), 0.012% cuprum (Cu) and 99.19% iron (Fe). The element of Mn at 0.365% on low carbon steel can bind the C elements, then carbide manganese (Mn_3C) are formed, which can increase the hardness properties of low carbon steel, so that the element of Mn and S must be maintained with a ratio of 10:1 whereas the combination of FeS can cause cracking in hot forging results.

Another element which can increase the hardness properties of low carbon steel is 0.192% Si but it is too fragile, so the Si element cannot be more than 0.1% [6]. Likewise, other elements that are impurities in the high carbon steel approximately equals to the low carbon steel such as: 0.005% S, 0.033% Al, 0.011% Cr, 0.012% Cu and 99.19% Fe in high carbon steel including ferrous metals (Smith, 1990). The element of 0.311% Mn at high carbon steel can bind the C elements. Thus it can form carbide manganese (Mn_3C), which can increase the hardness properties high-carbon steel, so that the element Mn to the elements of S must be maintained with a ratio between 10:1. Another element that can increase the hardness properties of high carbon steel is 0.23% Si, even it is also fragile. Due to that fact, the Si element cannot exceed 0.1% [6] and 0.013% P element on high-carbon steel is not fragile easily because it is still below 0.047% P.

Table 2 describes the chemical components and compositions of outer and inner materials tested using quantimeter before heating process in furnace and hot forging process. Meanwhile, Table 3 presents the result of measurement on wood charcoal heating temperature inside furnace (column 3) and metal scrap returns temperature during hot forging process using hammer (column 4).

TABLE 2

DATA OF CHEMICAL COMPOSITION TEST ON METAL SCRAP RETURNS BEFORE HOT FORGING AND QUENCHING PROCESSES

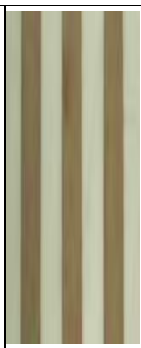
Metal Scrap Returns (Outer Material)					
Chemical Elements	C	Mn	P	S	Si
Chemical compo-sition (%)	0.132	0.365	0.007	0.005	0.192
Chemical Elements	Al	Cr	Cu	Fe	-
Chemical compo-sition (%)	0.033	0.011	0.012	99.19	-
Metal Scrap Returns (Inner Material)					
Chemical Elements	C	Mn	P	S	Si
Chemical compo-sition (%)	1.261	0.311	0.013	0.005	0.23
Chemical Elements	Al	Cr	Cu	Fe	-
Chemical compo-sition (%)	0.007	0.041	0.092	97.96	-

TABLE 3

DATA OF FURNACE HEATING AND HIGH TEMPERATURE HOT FORGING PROCESSES

No	**Furnace**	**Recrys-tallization Tempera-ture**	**Hot Forging Process**	**Hot Forging Tempera-ture**
1		935 ^{0}C		800 ^{0}C

2		935 °C		800 °C
3		935 °C		800 °C
4		935 °C		800 °C

1		29		71
2		28		72
3		31		70
4		25		66
5		27		69
6		31		69
7		29		70
8		27		71
9		26		70
10		31		71
	Average	28	Average Hardness Number, HR_B/HR_C	70 HR_B = 32,1 HR_C

Meanwhile, Table 4 presents the result of hardness test using Rockwell Hardness Number on outer material with B scale (HR_B) and inner material with C scale (HR_C) which tested on ten points. Average measurement was obtained before and after hot forging and quenching process. Meanwhile, Table 5 contains the data of average hardness rate measured using Rockwell Hardness Number. It indicates that the higher oil viscosity the lower the tensile strength hardness. The last data in Table 6 are the measurement of microstructure on testing specimen after hot forging and quenching process with oil variation: SAE 20, SAE 40, SAE 50, SAE 90. The results show pearlite phase (dark) with hard property, and ferrite phase (white) with tenacious property.

TABLE 4

HARDNESS TEST DATA BEFORE HOT FORGING AND QUENCHING PROCESSES

No	Hardness Number			
	High Carbon Steel (inner material)	**Hard-ness Num-ber (HR_C)**	**Low Carbon Steel (outer material)**	**Hardness Number (HR_B)**

B. Discussion

Low carbon steel 0.132% C has a number of average hardness of 32.1 HR_C which is lower than the number of high-carbon steel hardness 1.261% C average 28 HR_C (Table 3). Differences in the violence were influenced by elements of C affecting hardness properties, resilience and strength. According to the equilibrium diagram, Fe-Fe_3C low carbon steel 0.132% C including hypoeutectoid steel < 0.83% C which has a ferrite phase (α) the nature of soft, ductile and pearlite phase (α + Fe_3C) are hard, strong, ductile. Meanwhile, high-carbon steel including steel 1.261% C Hypereutectoid steel) > 0.83% C which has a pearlite phase (α + Fe_3C) and iron carbide (Fe_3C) in the form of a network. Hypereutectoid steel has high hardness properties but has lower strength compared to 0.8% C eutectoid steel ([7], [8]). Scrap returns as the the result of hot forging and quenching followed by medium oil: SAE 20, SAE 40, SAE 50, SAE 90, the general rate of violence tends to decrease. The highest hardness are on quenching type of oil SAE 20 of 53.5 HR_C and the lowest in quenching oil types SAE 90 of 49.6 HR_C.

From figures, hardness decreases due to the influence of the viscosity of the oil, thereby inhibiting the rate of cooling which is getting slower as a result the grain size the more rough (coarse) or grains of crystal-shaped neck is still rough and porosity of metal scrap returns results for hot forging have not been reduced, but major grain growing rough resulting in scrap returns more easily done because of its hot forging more resilient.

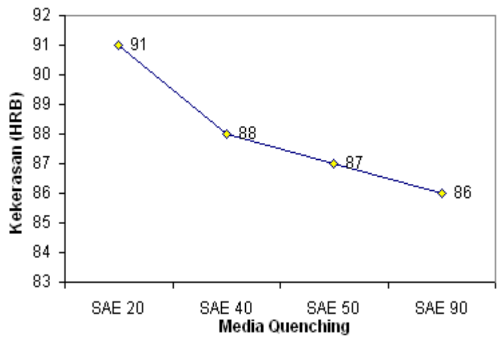


Figure 4. Hardness Scrap Results Hot Forging Returns to Media Quenching

The result of hot forging metal scrap returns and then quenching with oil media: SAE 20, SAE 40, SAE 50, SAE 90, tensile strength generally tends to decrease (Table 4) and at Figure 3, consequently the metal scrap returns more easily done hot forging due to its increasingly tenacious. The highest tensile strength is at quenching oil types SAE 20 tensile strength of 65 kg/mm2 and the lowest tensile strength of 53 kg/mm2 is at quenching oil types SAE 90 (Table 4) and Figure 5.

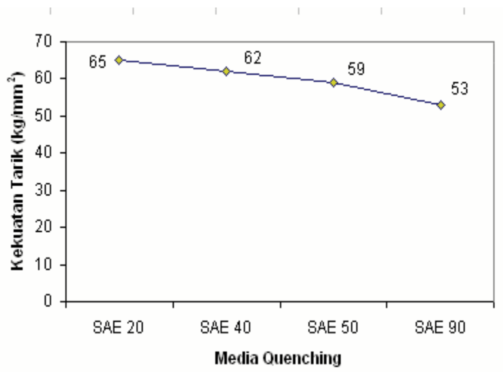


Figure 5. Tensile Strength Metal Scrap Returns as a result of Hot Forging to Quenching Media

Microstructure results of hot forging with quenching media type of oil SAE 20, SAE 40, SAE 50, SAE 90 with a magnification of 200x and general tendency of phase ferrite (α) (light color) are more dominant than the phase pearlite (α + Fe_3C) (dark color) (Table 5). The nature of the phase α has a resilient nature and low severity. Meanwhile, the phase α + Fe_3C have the nature of a hard and brittle. Quenching the results of hot forging with the media type of oil SAE 20, SAE 40, SAE 50, SAE 90 did not form martensite phase since it is very hard and brittle compared to the phase α + Fe_3C, due to the austenite phase (γ) cannot be transformed into a martensite phase which are hard and brittle.

A phase of unit cell has Body Centered Cubic (BCC) at temperatures below 910 ^{0} C. BCC is a solid solution consists of several C atoms that exist in pure iron and solubility of the C elements in phase a maximum of 0.025% occur under temperature 723 ^{0} C. But at room temperature, solubility of C was approximately 0.008%. Phase α + Fe_3C is an eutectoid mixture consisting of phase α and phase Fe_3C containing 0.8% C is formed at a temperature of 723 ^{0} C with BCC unit cell, [9].

V. CONCLUSION

Based on the testing, the utilization of scrap returns of scrap return metal material after hot forging and lubricating process: SAE 20, SAE 40, SAE 50, SAE 90 as a cooling medium is capable for obtaining the highest hardness of 53.5 HR_C at SAE 20 according to SNI 02-0331-1989 (KW II) with a tensile strength of 65 kg/mm^2. The lowest hardness was 49.6 HR_C at SAE 90 according to SNI 02-0331-1989 (KW II) and lowest tensile strength 53 kg/mm^2. In SAE 20, the more dominant microstructure of the pearlite phase (α + Fe_3C) is harder than the ferrite phase (α), whereas in SAE 40, SAE 50, SAE 90 is more predominantly formed ferrite phase (α) than the pearlite phase (α + Fe_3C).

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