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EFFECT OF HEAT TREATMENT ON TOUGHNESS OF TOOL STEEL(DHA1) FOR PUNCH TOOL

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Abstract— **DHA1 steel is one of the tool steels that is often used for making punch tools, but actually DHA1 steel must go through heat treatment first. In this study, the effect of heat treatment on the toughness of DHA1 steel was analyzed. The test method was carried out in 3 ways: First, specimen A was only grounded. The second way, specimen B is hardened and then tempered. The third way, specimen C was hardened and then tempered twice. After that, Rockwell hardness testing was carried out. Finally, the micro-structure was observed with an Olympus U-MSSP4 microscope. The results obtained: Specimen A is structured martensite (78.52%) and pearlite (21.48%) with a hardness value of 54.2 HRC, Specimen B is structured martensite (55.76%) and pearlite (44.24%) with a hardness value of 41.3 HRC, Specimen C is structured martensite (48.55%) and pearlite (51.45%) with a hardness value of 37.5 HRC. From these results it can be concluded that specimen B has the most optimal criteria tobe used as a punch tool.**

Keywords— **Punch Tools, Quenching, Rockwell C Hardness, Micro-structure, Tempering.**

I. INTRODUCTION

DHA1 steel is one of the high-quality tool steels that has characteristics equivalent to AISI H13 steel[1]. In its application as a punch tool, DHA1 steel must go through a heat treatment process before it can be used.

Attaullah (Ayooq) Arain, et al. (1999) conducted research related to the effects of austenitizing and tempering temperatures on the micro-structure, as-quenched and tempered hardness capabilities, and Charpy V-notch impact resistance of D2 and H13 tool steels. From the experiments and analysis conducted, it is concluded that (1) Increasing the austenitizing temperature resulted in coarsening of the grain structure, increased carbide dissolution, increased as-quenched and tempered hardness, and decreased impact toughness; (2) Tempering three times compared with two times after hardening in a controlled atmosphere furnace provides an increase in Charpy impact toughness of up to 25%; (3) D2 andH13 steels hardened at 1038°C followed by three tempering show relatively higher Charpy impact values than steels treated with one or two tempering. The resultant micro- structure of D2 and H13 steels after three tempering processes provides better plasticity than after two temperings[1].

Media Nofri, et al. (2017) conducted research on improving the quality of SKD 61 and ST 41 steel with the heat treatment process. To get the hardness required heating process, holding time, cooling media, proper hardening temperature and see the material comparison between SKD 61 steel and ST 41 steel before and after the hardening process on the properties of hardness and micro-structure. The results of the hardness test of SKD 61 steel material without heat treatment have a hardness value of 165 Hv, after hardening for 900°C temperature has a hardness value of 154 Hv, 950°C temperature has a hardness value of 152 Hv, 1000°C temperature has a magnification value of 161 Hv. The metallographic results show a change in the micro-structure of ST 41 steel where after hardening the pearlite structure looks more dominant after hardening the structure changes to bainite-ferrite[7].

Imam A. Suryana, et al. (2015) conducted a study that aims to analyze the effect of tempering temperature on the micro-structure and mechanical properties of AAR-M201 Grade E steel. The heat treatment process carried out is hardening-tempering. Followed by metallographic testing, tensile testing, hardness testing, and impact testing. The results obtained, AAR-M201 Grade E steel has a micro-structure of bainite, pearlite, and ferrite after hardening, and becomes tempered bainite after tempering. The most optimal mechanical properties were obtained when the tempering temperature used was 600°C, resulting in a tensile strength value of 828.88 MPa, yield strength of 735.64 MPa, elongation of 11%, reduction area of 31.35%, hardness of 27 HRC, and impact strength of 34 Joules at -40°C. The resulting mechanical properties almost entirely meet the AAR standard, except for the elongation value[3].

From the three examples of research previously mentioned, no research has been found that specifically discusses DHA1 steel. Therefore, this research will discuss the effect of heat treatment on the toughness of tool steel (DHA1) as a material for making punch tools. The test method is carried out with 3 kinds of heat treatment, hardening-tempering. After that, Rockwell hardness test will be conducted. Finally, micro-structure observations will be made on DHA1 steel specimens.

II. MATERIAL AND METHODS

A. DHA1 Steel Specification

In this research, the material used is DHA1 steel with the following chemical composition.

Table -1 Chemical composition

CHEMICAL COMPOSITION					
C	Si	Mn	Cr	Mo	V
0,4	1,0	0,5	5,0	1,3	1,0

DHA 1 steel is a complex alloy steel containing a large number of alloying elements such as Carbon (C), Vanadium (V), Molybdenum (Mo), Silicon (Si), Chromium (Cr), Manganese (Mn). DHA1 steel is a type of hypo-eutectoid high alloy steel, according to the Japanese Industrial for Standard, this alloy steel can be used for hot working tools steel process because it has the advantages of high heat operation, good toughness, and good wear resistance[7].

B. Heat Treatment Process

In this study, three heat treatment processes were used, namely hardening, hardening-tempering, and hardening-double tempering. The temperature of each heat treatment process in this study was determined from the specifications of the DHA1 steel material heat treatment temperature range data according to DAIDO provisions, and also from previous research literature studies. The heat treatment process parameters that will be used can be seen in Table 2.

Table -2 Heat treatment parameter

HEAT TREATMENT	SPEC.A	SPEC.B	SPEC. C	HOLDING TIME
Hardening	950°C	950°C	950°C	30
Hardening-Tempering I	-	530°C	500°C	60
Hardening-Tempering II	-	-	530°C	60

In the heat treatment process, when DHA1 steel is hardened quenching at the autenitizing temperature, it is expected that the steel has an increased hardness value, and when DHA1 steel is tempered, it is expected that the steel has toughness characteristics in the application process. The heat treatment scheme is shown in Figure 1.

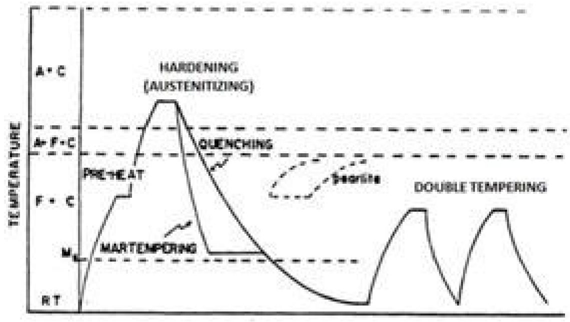

Fig. 1. Heat treatment scheme

C. Rocwell Hardness Tester

Hardness testing using the Rockwell method. Guided by ASTM E 18 - 2000, the Rockwell regular and Rockwel superficial hardness testing standard for metallic materials, works by indenting the surface of the test piece with a 120° angled diamond cone indenter. The indenter pressed into the object applies an initial load (small load), then applies a main load (large load), and releases the main load while maintainingthe small load. The initial load applies a load of 10 Kgf, while the main load has a load of 90 Kgf.

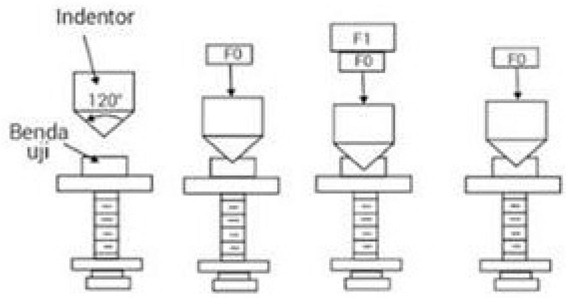

Fig. 2. Hardness rockwell tester

D. Metallography

The next test is to observe the micro-structure. An optical microscope is used to observe the surface of the specimen that has been previously etched. Micro-structure observation canbe adjusted for clarity by selecting the lens magnification that is available on the optical microscope.

Using a specimen that has been specially prepared until the surface of the specimen is shiny and reflects light like a glass surface. After that, it is given 5% Nital etching liquid based on ASTM E407, allowed to stand for a while before the etching liquid is rinsed with pure water or alcohol, after which it can only be observed through an optical microscope with a 200x lens magnification.

Calculation of the micro-structure crystal grain size composition refers to the ASTM E1382 standard which describes the test method for determining the average grain size using a light optical microscope and semi-automatic and automatic image analysis using software.

III. DATA COLLECTION

Based on the results of the hardness test in this study, the following data were obtained:

A. DHA1 Steel Hardness Value Data

Hardness testing is carried out by taking 3 test point samples on the surface of DHA1 steel specimens using the Rockwell C hardness method, after which the average hardness value is sought for each specimen, this aims to obtain more optimistic hardness value data.
Location of hardness test sampling points on each specimen:

Fig. 3. Testing point of hardnessTable -3 Hardness values

Table -3 Hardness values

SPESIMEN	HRC		
	MIN	MAX	AVG
Raw Material	36,6	37,2	36,9
Non Temper	53,0	55,0	54,2
Single Temper	40,0	43,0	41,3
Double Temper	37,0	38,0	37,5

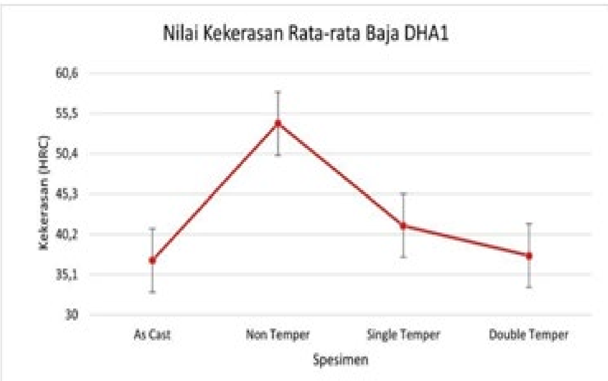

Fig. 4. Hardness line chart

B. Correlation between Hardness, Tensile Strength, andYield Strength Values

In this study, the hardness data obtained was used to obtain empirical equations for the calculation of tensile strength and yield strength in DHA1 steel[8] .

Table -4 DHA1 steel hardness, tensile strength, yield strengthvalues data

HARDENING TEMP	TEMPERING TEMPAT (°C)	HARDNESS (HRC)	TENSILE STRENGTH (MPa)	YIELD STRENGTH (MPa)	ULTIMATE STRAIN
As cast / Raw material		37,2	1263,1	959,0	0,043106
		36,6	1240,7	941,8	0,044449
		36,8	1248,2	947,5	0,043995
950 °C /30min	-	53,0	1991.2	1519.9	0.018971
		54,5	2084.6	1591.8	0.017399
		55,0	2121.9	1620.5	0.016823
950 °C /30min	530°C /60min	41,0	1401.3	1065.5	0.035987
		43,0	1479.7	1125.8	0.032682
		40,0	1363.9	1036.7	0.037733
950 °C /30min	500°C /60min	38,0	1289.2	979.2	0.041612
		37,0	1255.6	953.3	0.043547
	530°C /60min	37,5	1274.3	967.7	0.042456

In research conducted by E.J. Pavlina & C.J. Van Tyne, (2008), tensile strength has a linear correlation with Vickers hardness, HV, so it can be calculated using the formula[8]:
TS = -99,8 + 3,734HV
Description:
TS = Tensile strength HV = Vickers hardness
While the yield strength can be correlated with the hardness value pyramid using the Vickers hardness unit, HV, as:
YS = -90.7 + 2.876 x HV
Description:
YS = Yield strength HV = Vickers hardness

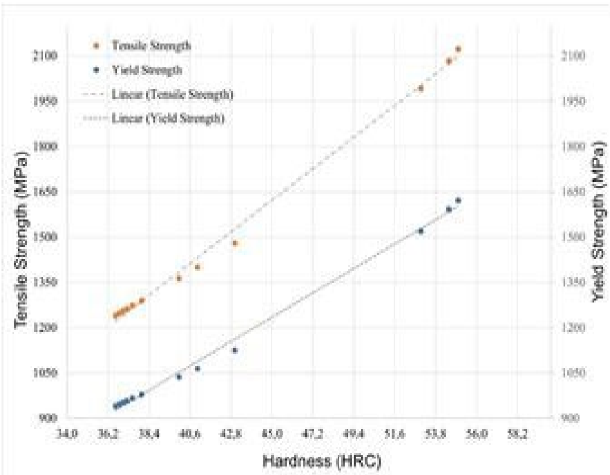

Fig. 5. Correlation of TS-YS vs Hardness value

To find the ultimate strain value, Xing-Qiang Wang, et al (2021) in their research suggested using the calculation formula[10]:

$\mathcal{E}u=(1+fy/315)-2.25$

Description:

$\mathcal{E}u$ = Ultimate strainfy = Yield strength

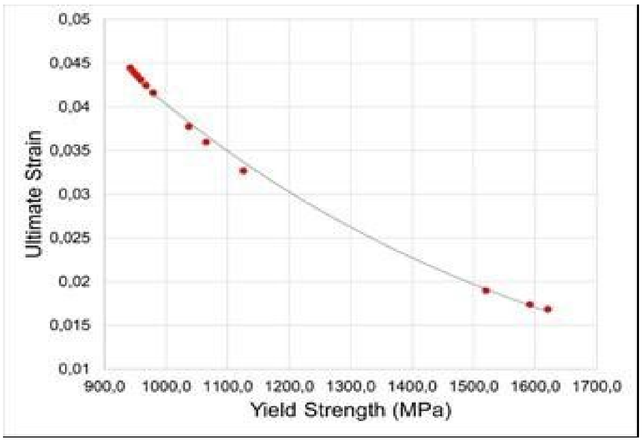

Fig. 6. Exponential correlation of ultimate strain vs. Yield strength

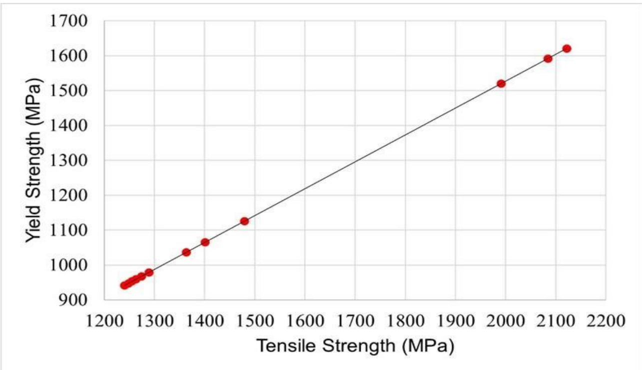

Fig. 7. Linear yield strength vs tensile strength correlation

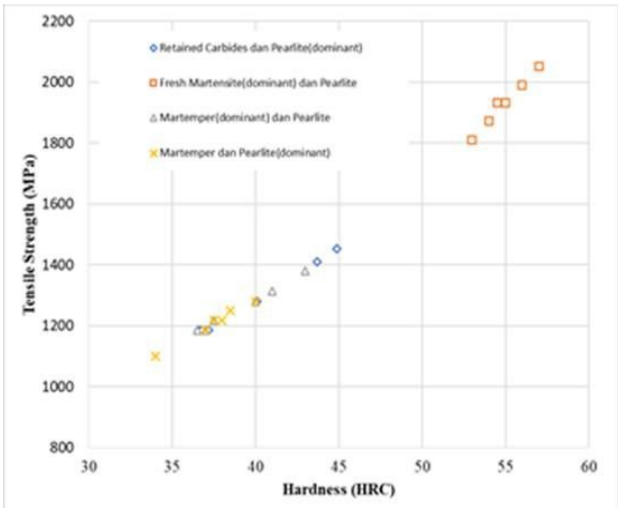

Fig. 8. Plot of tensile strength vs hardness based on micro-structure

C. Micro-structure Observations on Specimens

1) Micro-structure of specimen without heat treatment (rawmaterial)

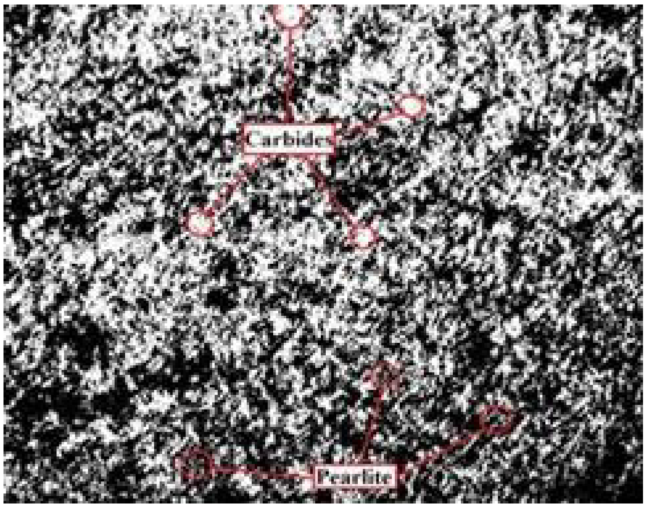

Fig. 9. Micro-structure of DHA1 steel raw material Figure 9 shows the results of micro-structure photos on specimens in conditions without any heat treatment. The visible phase is retained carbide and pearlite phase (α-Fe+Fe3C).

2) Micro-structure of specimen in the hardened condition Figure 10 shows the results of micro-structure photos on specimens in hardened condition. The visible phase is freshmartensite phase and pearlite phase (α-Fe+Fe3C).

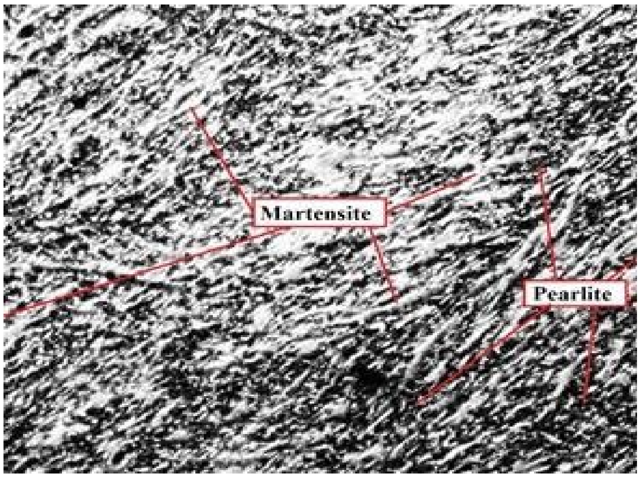

Fig. 10. Micro-structure of hardened DHA1 steel

3) Micro-structure of specimen in hardened and tempered condition

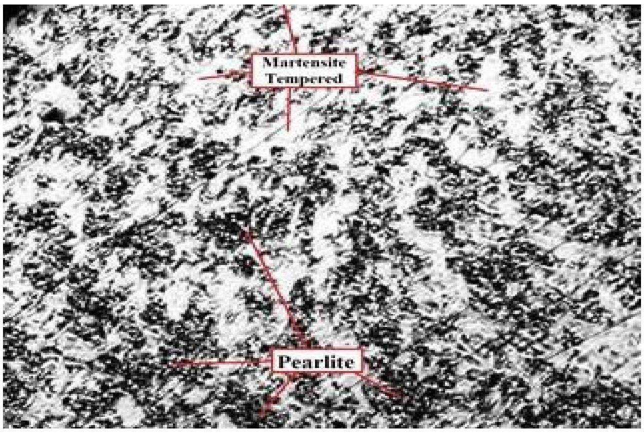

Fig. 11. Micro-structure of hardened and tempered DHA1 steel

Figure 11 shows the results of micro-structure photos on specimens in hardened and tempered condition. The visible phase is martensite tempered phase and pearlite phase (α-Fe+Fe3C).

4) Micro-structure of specimens in hardened and doubletempered condition

Figure 12 shows the results of micro-structure photos on specimens in hardened and double tempered condition. The visible phase is also martensite tempered phase and pearlite phase (α-Fe+Fe3C).

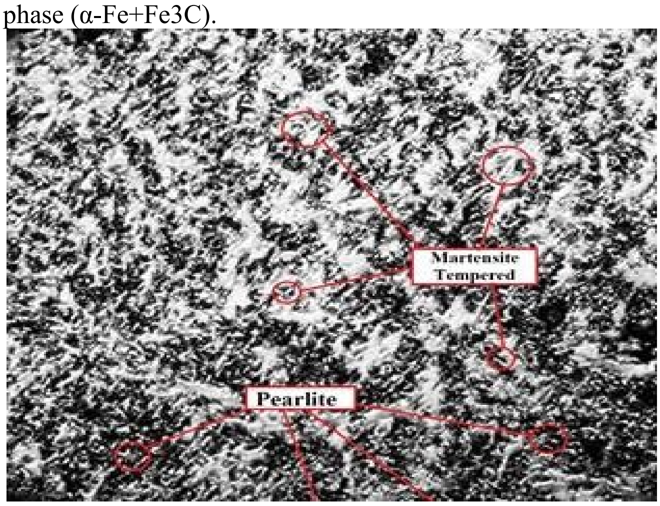

Fig. 12. Micro-structure of hardened and double tempered DHA1 steel

D. Automatic Calculation of Micro-structure Phase Composition

To calculate the phase composition formed in DHA1 steel with various heat treatment variations is to use Automatic Image Analysis (AIA) according to ASTM E1382 standard.

1) Phase composition of specimens without heat treatment (raw material)

Fig. 13. Retained carbide area of DHA1 steel raw material

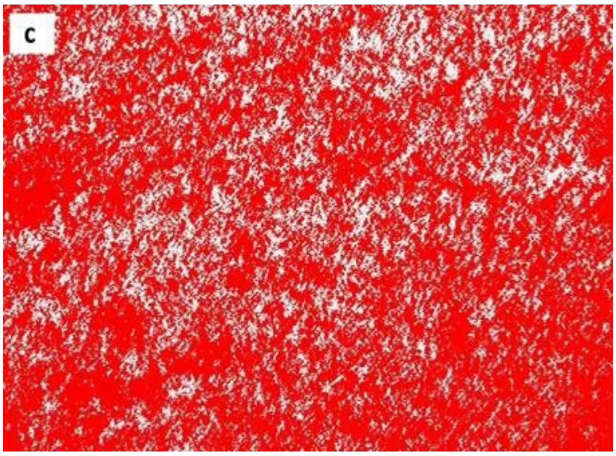

Fig. 14. Pearlite area of DHA1 steel raw material

Calculation of the phase area using image processing software, resulting in a calculation of the retained carbide areaof 30.89%. Calculation of pearlite area of 69.11%.

2) Phase composition of hardened specimens

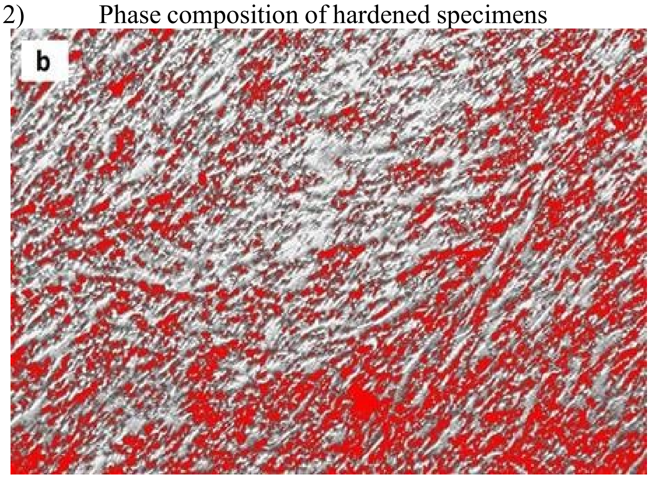

Fig. 15. Pearlite area of hardened DHA1 steel

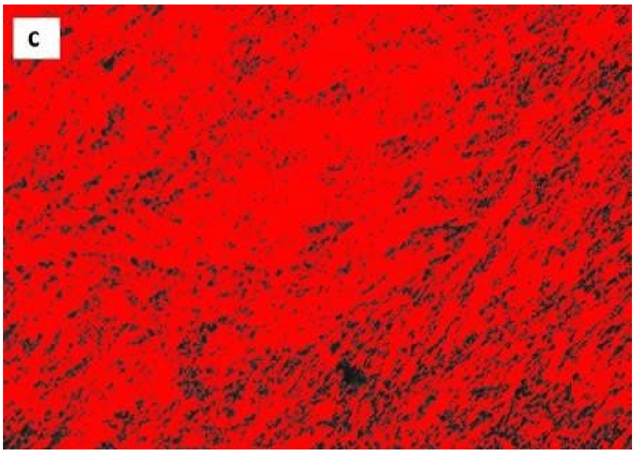

Fig. 16. Fresh martensite area of hardened DHA1 steel

Calculation of the phase area using image processing software, resulting in a calculation of the pearlite (α-Fe+Fe3C) phase area of 21.48%. Calculation of fresh martensite phase area of 78.52%.

3) Phase composition of hardened-tempered specimens

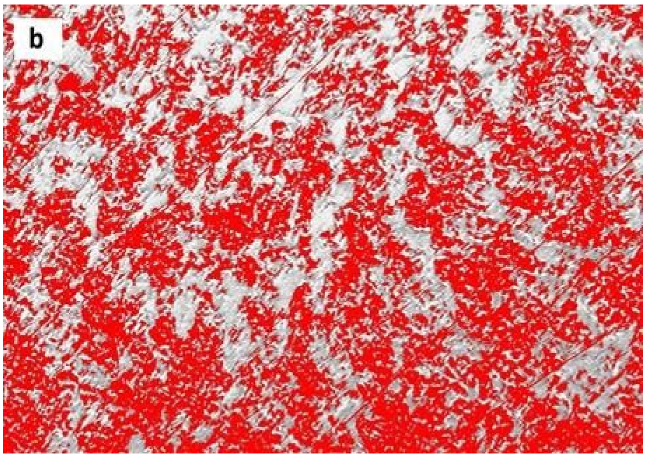

Fig. 17. Pearlite area of hardened and tempered DHA1 steel

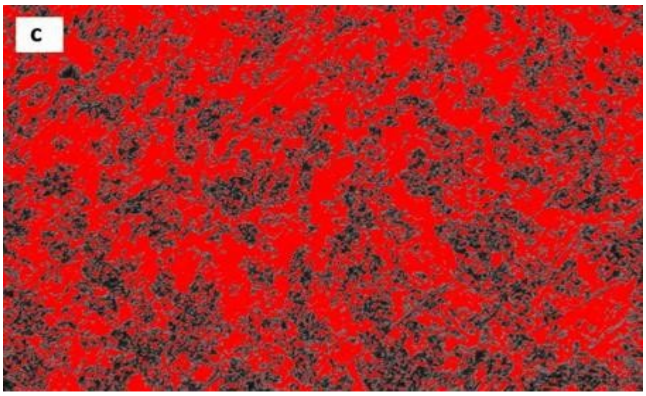

Fig. 18. Martensite tempered area of hardened and tempered DHA 1 steel

Calculation of the phase area using image processing software, resulting in a calculation of the pearlite (α-Fe+Fe3C) phase area of 44.24%. Calculation of martensite tempered phase area of 55.76%.

4) Phase composition of hardened-double tempered specimens

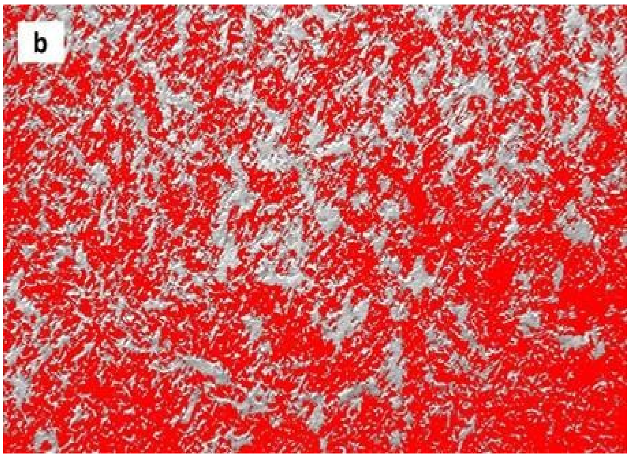

Fig. 19. Pearlite area of hardenend and double tempered DHA1 steel

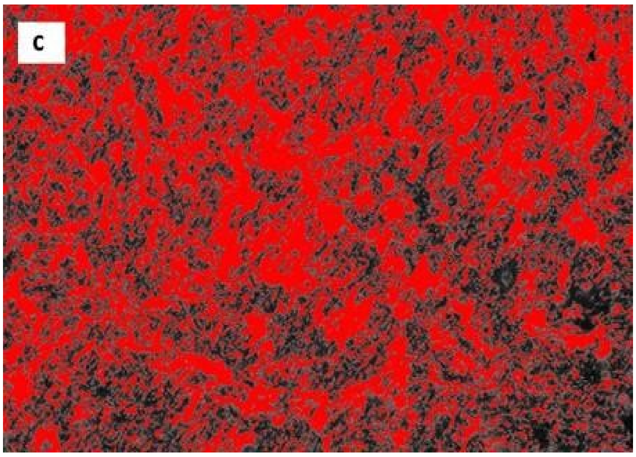

Fig. 20. Martensite tempered area of hardened and double tempered DHA1 steel

Calculation of the phase area using image processing software, resulting in a calculation of the pearlite (α-Fe+Fe3C)phase area of 51.45%. Calculation of martensite tempered phase area of 48.55%.

E. Discussion

1. DHA1 steel hardened condition

The heat treatment variation on specimen A is quenching hardening. As the data shown in Table 4.1. Where the hardness value of specimen A is 54.2 HRC, this explains that DHA1 steel after going through the hardening process has a significant increase in hardness from DHA1 steel without heat treatment which only has a hardness value of 36.9 HRC. As well as in Figure 4.9. shows that the microstructure's phase has change from pearlite (α-Fe +Fe3C) and retained carbide to fresh martensite phase of 78.52% and pearlite (α-Fe +Fe3C) of21.48%.

From the micro-structure, it can be confirmed that the characteristics of DHA1 steel in hardened condition are very hard and brittle[6], belonging to the martensitic steel category, not suitable for the application of punch tools and dies set components due to its inability to accept shock loads.

2. DHA1 steel hardened and tempered condition

The heat treatment variation on specimen B is quenching hardening. As the data shown in Table 4.1. Where the hardness value of specimen B is 41.3 HRC, this explains that DHA1 steel after going through the hardening and tempering process has a significant reduce in hardness from DHA1 steel without tempering process which has a hardness value of 54.2 HRC. As well as in Figure 4.9. shows that the microstructure's phase has change from pearlite (α-Fe +Fe3C) and fresh martensite phaseto martensite tempered (dominant) of 55.76% and pearlite (α-Fe +Fe3C) of 44.24%.

From the micro-structure, it can be confirmed that the characteristics of DHA1 steel in hardened and tempered condition are tough and good mechanical characteristic, with the most optimal toughness, very suitable for the applicationof punch tools.

3. DHA1 steel hardened and double tempered condition

The heat treatment variation on specimen B is quenching hardening. As the data shown in Table 4.1. Where the hardness value of specimen C is 37.5 HRC, this explains that DHA1 steel after going through the hardening and double tempering process has a slightly reduce in hardness from DHA1 steel with single tempering process which has a hardness value of 41.3 HRC. As well as in Figure 4.9. shows that the microstructure's phase has not change a form, just the size area of martemper and pearlite phase were change, dominant pearlite (51.45%).

From the microstructure, it can be confirmed that the characteristics of DHA1 steel in hardened and double tempered condition are tough but softer, although this can also be made as a punch tool, it is not optimal and tends to be morecomplicated for heat treatment.

IV. CONCLUSION

In this study, which discusses the effect of heat treatment on the toughness of tool steel (DHA1) for punch tools, the following conclusions can be drawn:

1) Heat treatment variations greatly affect changes in the micro-structure of DHA1 steel, in the condition without heat treatment DHA1 steel has a pearlite micro-structure (dominant)and retained carbide, in the hardened condition DHA1 steel has a martensite micro-structure (very dominant) and pearlite, in the hardened-tempered condition DHA1 steel has a martemper micro-structure (slightly more) and pearlite, in the hardened double tempered condition DHA1 steel has a martemper micro-structure (smaller grain size) and pearlite(slightly more).
2) In the hardening heat treatment variation, DHA1 steel is produced which has very hard and brittle characteristics so that it is not suitable for application in most engineering fields, in contrast to the hardening-tempering heat treatment variation which produces DHA1 steel characteristics with excellent toughness compared to only hardened conditions and qualified wear resistant compared to hardened-double tempered conditions so that it is suitable for application in punch tools and tool steels, While the hardened-double tempered heat treatment variation produces DHA1 steel with good toughnesscharacteristics and high ductility so it is suitable for application in the manufacture of dies molding or hot working dies press.

V. ACKNOWLEGEMENT

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