The Effect of Chemical Compositions of Tool Steel on the Level of White Layers Homogeneity and the Surface Hardness

K. A. Widi, I. N. G. Wardana, and W. Sujana

***Abstract*—The process of nitriding is commonly used in electronic hardware besides the automotive components. So far, there are still gains no optimum result. The atom diffusivity homogeneity effects on the material surface mechanical characteristics are yet to be done. The effecting factors like the composition of the chemicals elements in the materials are needed to be observed. In this paper the nitriding process on three types of tool steel materials with a different chemical composition was observed. The nitriding temperature and time is 550 0C and 4 hours, respectively. The white layer formed on the surface was indentified connected to their mechanical properties. The result showed that the hardness of materials is strongly affected by the stability or the homogeneity of the white layer in the surface. The homogeneity is strongly influenced by the chemical elements composition in materials. The highest hardness level, 975.5 HV occurs at the AISI P20 which shows the most homogeneous thickness surface due to Chrom composition of 2%. The next hardness level, 751.2 HV takes place in the AISI 4340 steel with 1.4 % Cr composition, and the lowest hardness, 720.8 HV occurs at the AISI 4140 with 1.07% Chrom.**

***Index Terms*—Chemical composition, nitriding, white layer, tool steel.**

I. INTRODUCTION

The limitation of nitrogen atom diffusion in producing compound layer and diffusivity layer to form the hard nitride layer are very low [1]. This thin layer has a very low toughness and breaks or cracks easily. The over time nitriding with the rate of hardened thickness formation of 2.5 μm per hour make the nitridation is less effective compare with the others heating process [2]. The hardness formed in every layer varies due to inhomogeneousity of diffusivity of the nitrogen atom. The inhomogeneousity is one of some factors that hamperes nitrogen atom diffusion into the materials. The layers contained the most nitrogen atom, generally in the upper layer is brittle.

Vitry *et al.* [3] shows the nitriding treatment to the mild steel using nitrogen gas produce the solid layer (~ 1600 HV), whereas that using ammonia gas results in poor mechanical character at outer layer. Nitriding for medical tool with CoCrMo compositon produced thickness, worn-out endurance, and the hardness in double. The process that was done at 500-800 ^{0}C for 9 hours forms the Cr_2N and CrN phases [4]. The number of nitrogen that form ε-nitride layer in the nitridation process is not only affected by the process but the most important one is the composition of chemical elements in nitriding materials [5]. Wu [6] observed behavior of austenitic type paramagnetic or ferromagnetic material (316L) based on their lattice. Transformation from paramagnetic to ferromagnetic behavior needs about 5% lattice parameter development achieved by adding 14% of nitrogen concentration in the super-saturated nitriding process. The utilization of fluidized bed to form nitride phase in the silica powder have been reported in [7]. It is reported that 5% Si powder does not produce β phase. 20% SiN /1300 ^{0}C or 30% SiN /1250 ^{0}C formed 21% β phase SiN [7]. The change of grain boundaries due to rolling process has a dominant role on the nitrogen atom diffusion in nitriding. The deformation of grain zise due to stronger rolling pressure reduces the diffusion of N. But at very fine grain zise the diffusion increses with rolling pressure. The higher temperature and nitride plasma improve the thickness of layer and their mechanical properties. The layer formed is the compound layer of δ-TiN, ε-$_{Ti2N}$, which is the diffusion layer with rich Al. The optimum result is obtained at the temperature of 800 ^{0}C in 5 hours [8-9]. Ben Slima [10] showed that stiffening before ion and gas nitriding to the tool steel material improve the depth of white layers. Multi-stage nitridation at 550 ^{0}C and 530 ^{0}C on the H13 steel make the white layer appear in the surface of the material at 5 micron caused by the highest nitrogen concentration. The diffusion layer at 70-80 micron contains precipitation of nitride in the grain and the grain boundaries. The temper martensit structure present in the core of the grain. Zach et al [11] also reported the influence of gas temperature and super-saturated steam using Poisson equation. They reported that very high expansion ratio does not have apparent effect.

In this paper, the effect of chemical element composition to the formation of white layer which form in the surface and its hardness in nitriding process is discussed.

II. EKSPERIMENTS

The specimens tested in this experiment were AISI P20, AISI 4340 and AISI 4140 tool steels. The chemical compositions of the specimen are shown in table 1. The dimension of the specimen is 5 cm diameter and 5 cm height. The specimens were processed with nitridation in fluidized bed reactor (Fig. 1) with 30% NH_3 and 70% N_2 with total flow rate of 0.6 m^3/hours. The temperature of the process was 550 ^{0}C in 4 hours. The hardness of specimens was measured by micro-hardness tester at 5 points and the

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specimens' microstructure was recorded using 250 times of micro structure zooming. The correlation between the layer type and the hardness was analyzed.

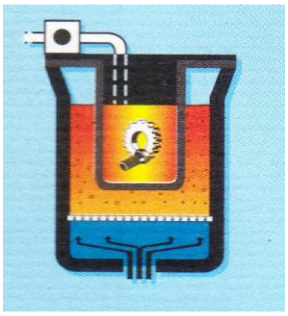


Fig. 1. Fluidized bed reactor

TABLE I: COMPOSITIONS OF SOME TOOL STEELS

Material	Chemical Compositions					
	C	Si	Mn	Cr	Ni	Mo
P20	0.37	0.3	1.4	2.0	1.0	0.2
4340	0.36	0.25	0.7	1.4	1.4	0.2
4140	0.41	0.34	0.81	1.07	-	0.19

Experimental procedure

Tool Steels with different chemical compositions
Specimen Preparation
(sectioning, grinding and polishing)

↓

Experiments
(550 ^{0}C, 4 hours)

↓

Characterization
Metallographic, micro-hardness

↓

Results Evaluation
Selection of optimum chemical compositions for nitriding

III. RESULT AND DISCUSSION

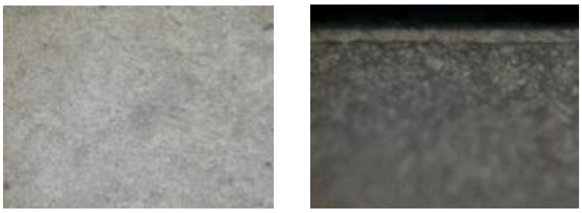
Hardened layers with different morphologies were observed at each specimen. Each layer gives different hardness as in table 2. The difference has correlation with chemical composition as in table 1. Fig. 2-4 shows that layer thickness homogeneity is higher at higher chrome content in the tool steels.

The specimen preparation is the other factor that is very important to produce the layer in the surface of materials. The flat surface gives a high chance to produce the homogeneous diffusion of N atom to the whole surface simultaneously. The metallographic test showed that the uneven surface result the uneven layer. The roughness reduced the optimum result of an average hardness value from the materials.

The chemical composition has a role in the homogeneity of atom diffusivity to the materials. Formation of super-saturated reaction NH_3 gas hampered the diffusion of N atom. The super-saturated reaction is resulted from rebound of N atoms to form N_2 molecule because there is not enough space available for the atoms. The space availability for the atoms is proportional to the capacity of chemical composition in material to form the nitride compound. As shown in table 1 the composition of chrome atom which has highest hardness in the specimen is the highest. So it can be concluded that Cr gives enough space for N atoms to diffuse into the specimen. The trend is shown in Fig. 5. The AISI P20 with the highest Cr content, 2% has the highest hardness increase after nitriding. The next is AISI 4340 and AISI 4140 with Cr composition of 1.4% and 1.07%, respectively.

TABEL II: HARDNESS BEFORE AND AFTER NITRIDING

Type Tool Steel	Before Nitriding [HVN]	After Nitriding [HVN]
P20	319,0	975.4
4340	341,0	751.2
4140	296.4	720.8

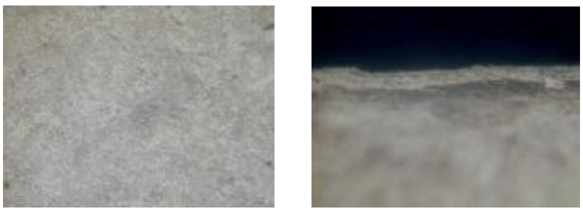


(a) (b)

Fig. 2. AISI P20 Microstructure (250x) a) before, b) after nitriding

(a) (b)

Fig. 3. AISI 4340 Microstructure (250x) a) before, b) after nitriding



(a) (b)

Fig. 4. AISI 4140 Microstructure (250x) a) before, b) after nitriding

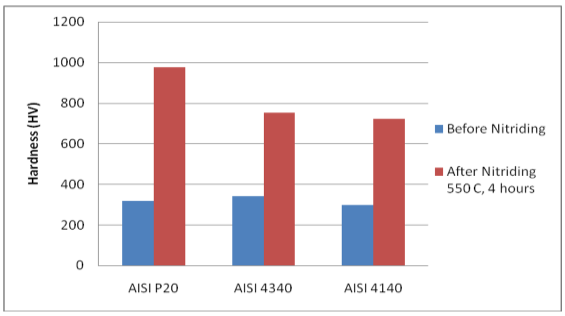
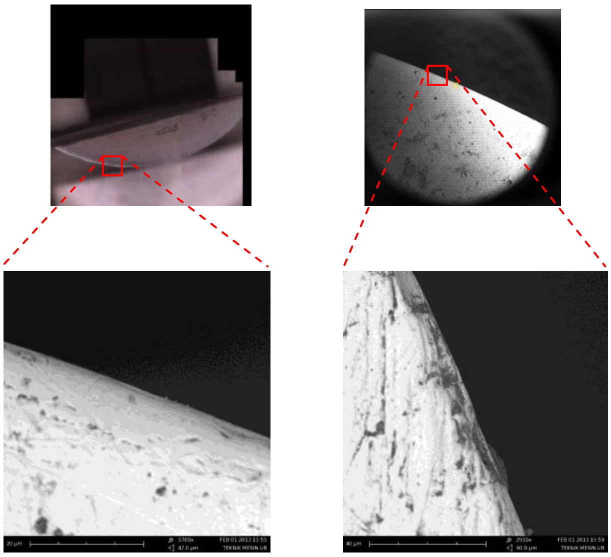


Fig. 5. Hardness of some tool steels before and after nitriding process



a) b)

Fig. 6. SEM Analysis on white layers a) AISI P20 b) AISI 4340

It can be concluded that the nitrogen atoms diffusion into the material and the bonding prevention between the atoms can be intensified by increasing the chemical composition that has bonding strength with N larger than bonding energy between N atoms. This promotes the nitride formation. Liberation of N atom is affected not only by the internal factor of material but also by the external effect. Too much N atom diffused to the materials caused the N atom have a less chance to bond with the atom of composition elements. The other possible effect is the uneven spread of the passive layer that can affect the homogeneity of nitrogen atom diffusion into the material. The material tested is the composition material which has a good passive layer for corrosion endurance. The heating of the material just stretches the bond od atoms. The heating energy only 1/25 of the total energy needed to break the bonding.

Fig. 6 Shows that AISI 4340 is more porous on the top of white layers. Therefore, we can conclude that nitrogen concentration in the white layers is supersaturated.

IV. Conclusion

The surface hardness resulted from the nitriding process is affected by the homogeneity of white layer in the whole material surface. Flatter layer has betters hardness value indicating that the hardness value is not only affected by the thickness of white layer. The homogeneity of white layer is affected by the Cr content. The AISI P20 steel has the highest composition of Cr element with better white layer homogeneity. The other composition element in the tools steel has a minor role on the white layer homogeneity level.

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