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MICROSTRUCTURAL AND MECHANICAL PROPERTIES AL 6061 PROCESSED BY COLD ROLLING AND AGING

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ABSTRACT

An Aluminum alloy 6061was produced by cold rolling and subsequently aging. Cold rolling is used for reducing grain size and aging is used for producing second-phase, thus improving hardness, strength and wear resistance. In the present paper, a process through cold rolling with reduction of 50%, 60% and 70% in thickness then aged at 2000C for 1.800, 3.600, 5.400, 7.200 and 10.800 sec. Microstructural analysis shows that the grain morphology consists of equalized grain for as-received samples and elongated grain for sample after cold roll and aging. X-Ray Diffraction (XRD) analysis showed peaks phases in Al 6061 after cold rolled and aging. Hardness measurements showed that combination between small grain size and presence of second-phase led to a significant increase in the hardness. Maximum hardness of 121 HBN is achieve for sample after cold roll 70% and aged for 5400 second. The wear resistance testing showed that lost particles of 6,209951 x 10-6 mm3/mm for received sample and 4,775436 x 10-6 mm3/mm for sample after aging process. It is showed that high hardness related to increase the wear resistance. It is reasonable that the presence of second phases are function as obstacle for dislocation movement.

Keywords: microstructural; mechanical properties; Al 6061; cold rolling and aging

INTRODUCTION

Aluminum (Al) has been used widely in military, aerospace and automotive industries that required light weight and good corrosion resistance. Aluminum has become the material of choice for aircraft's industry since 1930's [ ]. Generally, the aircraft's industry used Al 2xxx and 7xxx series as a material for aircraft's components. However, since Al 6061 is becoming increasingly widespread applications with many advantages such as good formability, excellent corrosion resistance, good weld ability, and low price, Al 6061 becomes an alternative material for aircraft components, in this case the suitable part is skin of airplane wings [1, ,]. Al 6061 compared to Al 2xxx and 7xxx series is much lower strength. Then, we need to find suitable procedure for improve the mechanical properties of Al 6061. In order to achieve the maximum mechanical properties, required suitable heat treatment, there effective method are cold rolling and aging. Heat treatment is one of the alternative methods that can be used to increase strength without alloying. In this study, the heat treatment used is cold rolling and aging. Cold rolling cause deformation of the material characterized by reduced material thickness. When the deformation occurred, the dislocations movement. The concentration of dislocations becomes dislocation pile-up, thus the mechanical properties increase. Unlike the process cold rolling, strengthening of material through the process of aging, generated through precipitation strengthening. In Al 6061, Mg2Si is precipitate formed by aging. This precipitate has function as barrier of movement of dislocations, which increasing its mechanical properties. When cold rolling was combined with aging, both of them will completing each other.

The aim of this work is to determine the effect of cold rolling and the aging process on microstructural and mechanical properties of Al 6061. Despite the cold rolling and aging process of Al 6061 has been studied previously but understanding of these processes is still incomplete because of the compositions, processes and parameters used affect the results obtained.

EXPERIMENTAL PROCEDURES

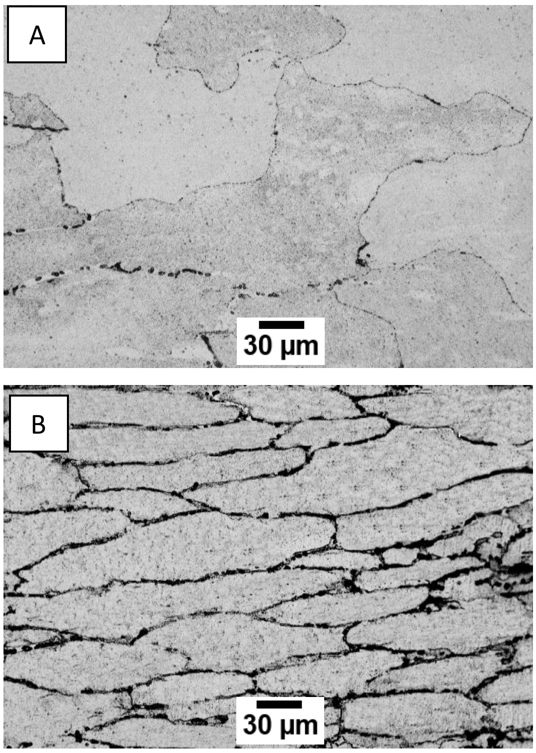
The aluminum 6061 as received material with dimension length x width x height = 50mm x 15mm x 10mm. The composition of Al 6061 used in this study is given in Table 1. Samples were characterized using metallography examination, X-ray Diffraction (XRD) analysis, hardness and wear resistance testing. Metallography examination was carried out using optical micrograph Olympus BX51M. Before that, the samples were prepared. The samples were ground with silicon carbides paper from 320 grit, 500 grit, 600 grit, 800 grit, 1000 grit, dan 1200 grit for 1-2 minutes. After that, the samples were polished with 1 μm diamond spray using polishing machine. The last one, the samples were etched with Keller reagent and composition consist of 25 ml of water, 5 ml of HF, 7.5 ml of HCl and 12.5 ml of HNO3 immersed for 50-60 sec. Then, microstructure was observed using optical micrograph. X-Ray Diffraction (XRD) analysis was performed using the Cu Kα. Hardness measurement was determined using Brinell hardness testing with 2,5 mm steel ball in diameter and 62,5 kg loads for 1 minute 17 second in each point. Wear resistance was measurement using Ogoshi Tokyo Wear Testing Machine according to ASTM G99 standard. Then, samples were solution treated for 1 hr at 5300C and quenched in ice water. After solution treated, the sample were always kept in freezer to eliminate the detrimental effect of natural aging. Next, the samples processed by cold rolling with reduction of 50%, 60% and 70% in thickness using roll machine. Then, artificial aging was carried out at 2000C for 1800, 3600, 5400, 7200 and 10.800 sec.

Table 1. Chemical Composition of Al 6061

Si	Mg	Fe	Cu	Cr	Zn	Ti	Other elements	Al
0,63	0,98	0,19	0,18	0,05	0,10	0,08	0,15	*Balance*

RESULTS AND DISCUSSION

Figure 1 shows the microstructure of Al 6061: (a) as received, (b) after cold rolled, (c) after the cold rolled and aging. Microstructure of Al 6061 as-received is equaxial, then changed to a elongated grains after cold rolled and back into equaxial after the aging with micron scale grain size. Grains Al 6061 as received is very coarse grain with size about 200 μm and after cold rolled and aging turns into equaxial grains with a size about 36.28 μm.



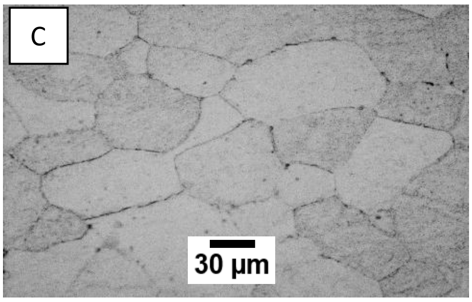


Figure 1. Microstructure of Al-6061 (a) as received, (b) as rolled, (c) after aging

Grain size changed become finer after solution treated. This case occurred because of this temperature process was above the recrystallization temperature. This aim of this process is to eliminate the previous treatment of the sample and to produce a new finer grain and new lattice free strain. After recrystallization process is completed, rise new grains replaced all the grain before. If the temperature is raise, grains will be enlarged by consuming grains with a smaller size, so the size with smaller grains will slowly shrink and then disappear altogether.

Figure 1 shows the microstructure of Al 6061 after cold rolled with reduction in thickness: (a) 50%, (b) 60%, and (c) 70%. Items result showed elongated grain and most length at 70% reduction in thickness with average grain size about 34,6 μm. Normally, do not occur refining grain size in Al 6061, because the treatment temperature used below the recrystallization temperature except when the solution treatment. Grains only elongated to the direction roll and after aging, grains changed into equaxial.

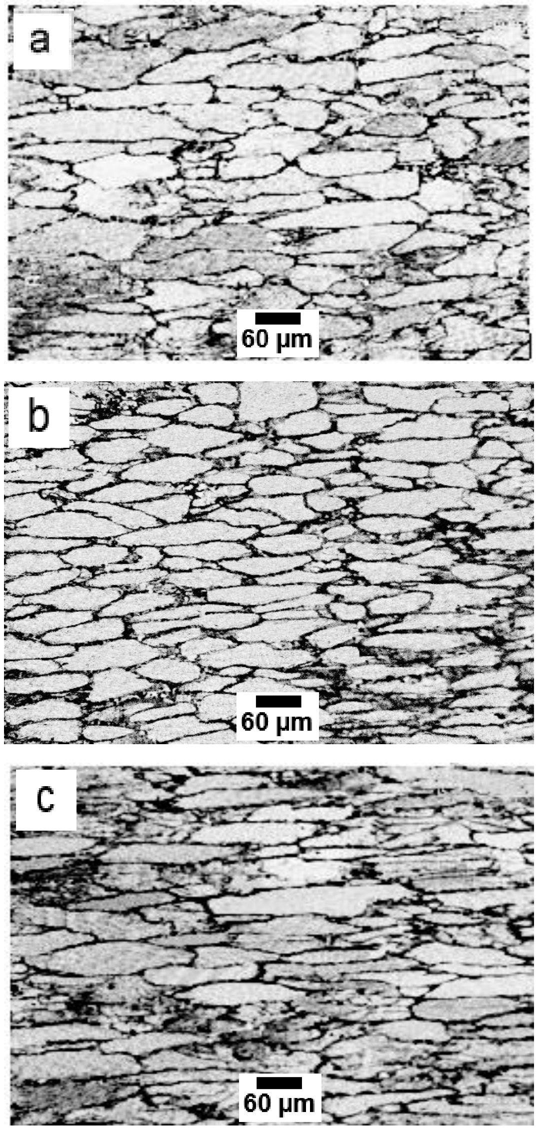


Figure 2. Microstructure of Al-6061 after cold rolled with reduction in thickness (a) 50%, (b) 60%, (c) 70%

Figure 2 shows X-Ray Diffraction (XRD) profiles of Al 6061 after cold rolled and aging with reduction in thickness: (a) 50%, (b) 60%, (c) 70%, for 1800 (a), 3600 (b), and 5400 sec. (c) is included sample as solution treatment. XRD profiles show that there are three phases in Al 6061 after cold rolled and aging and single phase on Al 6061 as solution. Phases include Al, Mg2Si, and Al2FeSi. Al2Fesi and Mg2Si phases identified as second phase in Al 6061.

However, the second phase was present in very low peak intensity, so that the peaks are not seen. Therefore, the peaks were magnification indicated by arrows as shown in Figure 4a, 4b, and 4c. In Al 6061 as solution was found only single phase, namely Al. As we know that the purpose of the solution treatment at Al 6061 is to equalize the phases contained in a sample by dissolving the entire phases of both, so only found single phase Al and grain re-grow into new granules.

The second phase was present either on Al 6061 cold rolled reduction of 50%, 60% or 70%. Overall, this second phase was found in all samples with the same lattice planes. Both the reduction of 50%, 60% or 70%, there are no significant difference in peak intensity. Except the 60% reduction in aging time of 1800 sec, the second phase Mg2Si peak does not appear (Figure 2b) and emerging on the aging time of 3600 and 5400 sec.

The Highest intensity of Al 6061 peaks after cold rolled and aging is at the Bragg Angle 38.4090 with a lattice plane (111) for the reduction of 50%, 60% and 70%. Whereas, sample Al 6061 as solution, highest intensity of Al 6061 peaks emerges at Bragg Angle 64.9820 with lattice planes (022). This shows that the highest volume fraction of Al is in the lattice plane (022) in Al 6061 as solution and (111) for Al 6061 after cold rolled and aging.

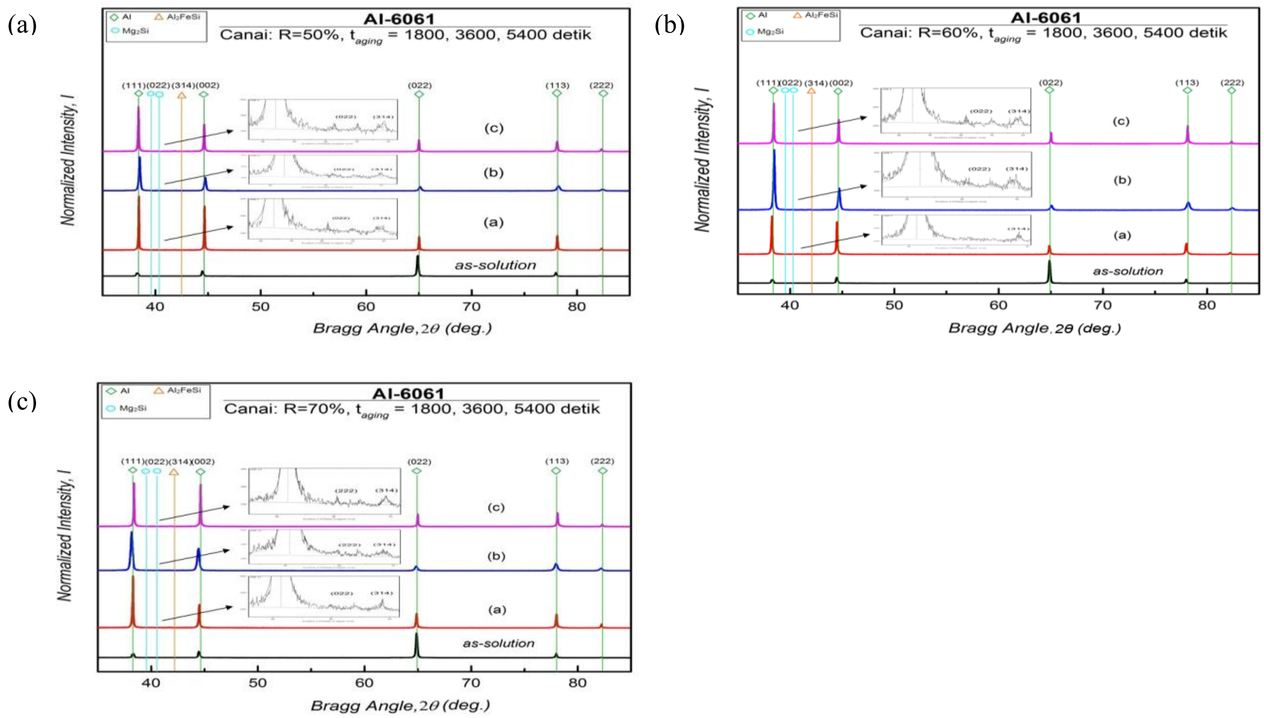


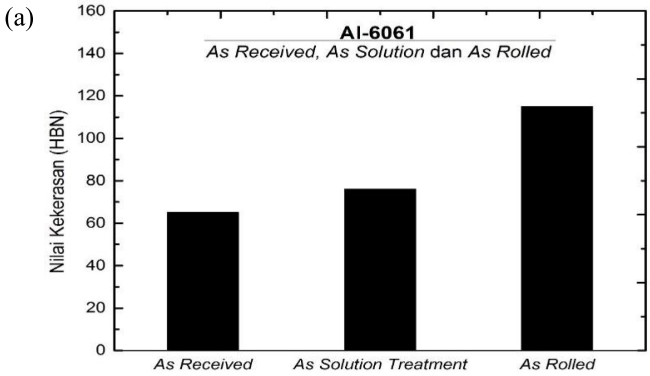
Figure 3. X-Ray Diffraction (XRD) profiles of Al 6061 after cold rolled with reduction in thickness (a) 50%, (b) 60%, and (c) 70% for aging times 1800 (a), 3600 (b), and 5400 sec. (c) included sample as-solution treatment

The width of the peak in the XRD profile shows no significant difference. As we know, that broadening peak will affect the mechanical properties of the material [,]. But in this case there are no significant difference. This indicates that the role of the second phase does not significantly affect the mechanical properties of Al-6061.

Figure 3 shows hardness for Al 6061: (a) as received, as solution treatment, and as rolled; (b) after the cold rolled and aging. Figure 5a shows hardness of Al 6061 samples as received, as solution and as rolled an increased hardness consistently. Hardness of Al 6061 as received, as solution treatment and as rolled (as rolled) are 65 HBN, 76 and 115 HBN respectively. Al 6061 as received has low hardness. However, hardness increased after solution and more after cold rolled. As explained before, Al 6061 as received has a very coarse grain size, but after solution treatment, grains were recrystallized then form a new single phase that has grains finer, so the hardness increases. After Al 6061 processed cold rolled, Al 6061 plastically deformed that cause the grains changed become elongated grains. When Al 6061 plastically deformed by cold rolled, the density of dislocation and lattice strain were increased. Those things that cause an increase in the mechanical properties of Al 6061. It is also stated by previous studies conducted on Al 5083 [ ], Al 6061 [ ] and AA1050 / AA6061 composite [ ].

Solution treatment produces new grains free strain and finer because temperature process is above the recrystallization temperature. In the finer grains, there are more grain boundaries which nucleation places of new grains. If the total area of grain boundaries increase, the material will be stronger because the grain boundaries have function as obstacle of the dislocations movement. Dislocations make it more difficult to move. This is consistent with the results of hardness testing and metallographic results performed. The hardness after solution treatment increased from the initial conditions. When viewed from the microstructure, the microstructure of Al 6061 after cold rolled and aging has finer grains than as received. That are things that causes hardness increased.

Plastic deformation processed by cold rolling causes a rise of energy in the form of high dislocation density. The dislocation density (pile up of dislocation) causes more lattice strain. This lattice strain causes the lattice irregularities. The level of irregularity in the lattice will lead to improved mechanical properties of Al [3]. This is consistent with hardness obtained. Hardness increased after the cold rolled on Al 6061.



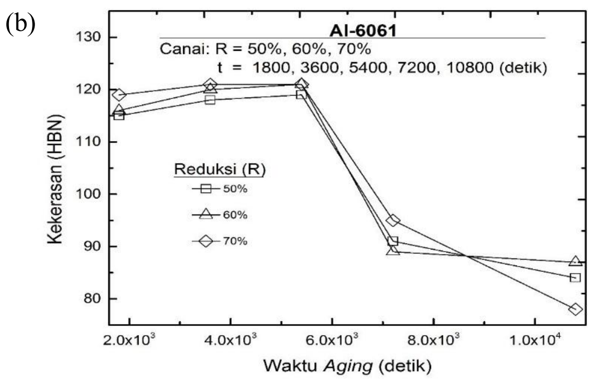


Figure 4. Hardness of Al 6061 (a): as received, as solution treatment, and as rolled (b) after cold rolled and aging.

Figure 4b shows hardness of Al 6061 after the cold rolled and aging. Unlike Figure 5a, this picture shows no significant hardness increasing after aging. Increased hardness of Al 6061 after aging caused by the presence of a second phase. This is consistent with the XRD profiles. Overall, XRD profiles show that there are other phases than Al. There are Mg2Si and Al2FeSi. This phase called second phase and Mg2Si is precipitate which formed after aging. Precipitate has function improving the mechanical properties of Al 6061 by blocking the movement of dislocations in Al when subjected to deformation. Therefore, Al become stronger [1, 3, , , ,]. However, in this study, the hardness does not show significant improvement. There may be a less effective because of the aging resulting precipitates are not spread evenly on Al 6061 or caused by the large size precipitates. The precipitate visible when using Transmission Electron Microscopy (TEM) based on previous studies on Al 6061 [4, , ,]. Hardness increased with percent reduction and aging time increase. The high hardness is 121 HBN obtained at 70% reduction in thickness with aging time of 5400 sec. Other side, the hardness also decreased with aging time. It is reasonable that the decrease of hardness due to over aging phenomena. From the picture can be seen that after performed aging at 7200 and 10.800sec, hardness decreased. This is consistent for all of the reduction variable. Lowest hardness reached on 70% reduction in thickness with aging time 10.800 sec. The phenomenon of the decreased of hardness during aging after reaching peak hardness called over aging [10]. According to Gunduz Demir H. & S. [2], the addition of aging time can decrease the value of hardness. When over aging, precipitate became larger and caused the function of this precipitate became weaker to blocking dislocation movement, so the mechanical properties will decrease. It is also stated in previous studies for Al 6061 [11,14] and Al 6063 [11]. Over aging phenomenon can be demonstrated using Transmission Electron

Microscopy (TEM) but in this study was not done.

Table 2 shows the wear resistance test results for Al 6061 as received and Al 6061 after cold rolled and aging. Improved mechanical properties not only in hardness, but also on the value of the wear resistance. The rate of wear resistance samples as received faster than samples after cold rolled and aging. This indicates that Al 6061 as received more susceptible to wear than the Al 6061 after cold rolled and aging. The volume of material eroded much more on Al 6061 as received. Trace width of the eroded material is also greater in Al 6061 as received. So it can be concluded that the process of cold rolled and aging increase the value of the wear resistance of Al 6061.

Table 2. Wear Resistance of Al 6061 after cold rolled and aging

Sample name	Abrasive width (mm)	Abrasive volume (mm^3)	Wear rates (mm^3/mm)
As-Received	3,34	0.6209	6.209951×10^{-6}
Aged	3,06	0.775	4.775436×10^{-6}

Wear resistance is closely related to hardness. Samples after treatment had higher hardness than samples as received. When the hardness is high, it becomes difficult for the Al 6061 material deform by other material.

SUMMARY

The primary conclusions obtained from this study can be summarized as follows:

1. Grains of Al 6061 changed from equaxial become elongated grain (after cold rolling) and returned back become equaxial after aging.
2. Hardness of Al 6061 increased become 115 HBN (after cold rolling) and 121 HBN (after aging), the same thing also happened in wear resistance of Al 6061. The wear resistance increased from 6.209951 x 10-6 (Al 6061 as received) to 4.775436 x 10-6 (Al 6061 after cold rolling and aging). This is due to the mechanism of strain hardening and the presence of second phases Mg2Si and Al2FeSi.
3. Decreased hardness occur after the aging time of 7200 and 10.800 sec, it is probably due to over aging.

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