Effect of Cold Work on the Age Hardening Behaviour of Al 2014 Al alloy

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Abstract-The Al 2014 alloy was hardened to a considerable extent by subjecting it to solution-heat treatment at 502C° for 2 hours water quenching and then aging, both natural and artificial. Hardness increased to 113HV from the as-cast value of 85HV during natural aging and increased further to 136HV and 145HV when aged at 180C° and 232C° for only one hour. The hardness increased significantly when the alloy was cold worked to various degrees by rolling after solution treatment and water quenching, and then artificially aged. Maximum hardness values obtained were 188.7HV and 191.6HV which corresponded to 44% and 48% cold deformation respectively at the aging temperature of 180C° for only one hour aging time.

Keywords-Aluminium Alloy, 2014 Aluminium Alloy, Cold Rolling, Age Hardening

I. INTRODUCTION

Aluminum and its alloys have many useful applications due to their excellent combination of properties such as the low density, the good resistance to atmospheric corrosion and high ductility [i]. Due to the use of high strength and age hardening properties, aluminum alloys are common in aerospace industry. These alloys are selected due to their useful combination of physical and mechanical properties which include strength, ductility, fatigue resistance, fracture toughness, and corrosion resistance. In order to obtain the desired set of alloys properties, the correct combination of alloy composition and thermo mechanical processing is essential [ii].

Aluminum 2014 is used for many important structural components of the air craft. This alloy is similar to 2017 and 2024 with respect to a high percentage of copper. It is used where high strength and hardness including service at elevated temperature is required than what can be obtained from 2017 or 2024. [iii]

Aluminum and copper alloys of 2xx series are widely used for their good mechanical strength in the solution treated and artificially aged condition. When loaded near to or above the aging temperature, over-aging process occurs and depletes material properties such as hardness and tensile characteristics [iv].The mechanical properties of Al 2014 and similar alloys could be significantly improved by using precipitation hardening heat treatment [v].

Aluminium alloys have been the major material for the structural components of airplane for more than 80 years because of their well-established design methods, well known performance, manufacturing and reliable inspection techniques [vi]. Aging treatments significantly increase properties of some of Aluminum alloys and their composites, especially of 2xxx and 6xxx series alloys. [vii] Many structural 2xxx aluminum alloys with high Cu and Mg ratios contains Cu in excess of 2 percent by weight and precipitation hardening is the main strengthening method in similar alloys. However, from a durability and corrosion perspective, there are increasing concerns regarding Copper rich Aluminum-alloys,asit is found that higher Cu content associates to relatively low corrosion resistance. There is an emergent concern in Al Mg Cu alloys that posess low amount of Cu and high Mg contents and show improved age hardening responses for emerging automotive applications. [viii]

Reference [ix] studied the influence of cold working and age hardening on Al 6061. It is found that single aging at 180 degree for four hours can improve the strength and mechanical properties but double aging has no effect. [x] compared the effect of cold working on Al 2024, 6061 and 7075 alloys and stain limits are suggested. Forming could be achieved for the tempers that provide low strength and high conductivity. Reference [xi] studied the influence of microstructure on work hardening of Al Mn alloy and one Al Mg Sialuminum alloys and results showed that microstructure had a marked influence on both ductility and work-hardening. Reference [xii] investigated the effect of cold deformation on the age hardening behavior of 2024 Al alloys. It was found the aging behavior is accelerated by large cold deformation and peak strength value could be attained for the aging of 40 minutes.

Reference [xiii] studied the effect of homogenization on cold deformation of 6063, 2014 aluminum alloy by torsion test. This technique has large effect on the microstructure of aluminum alloys and decreases the secondary phase. The extent of cold deformation is improved by homogenization process.

Reference [xiv] determined the effect of large plastic deformation and age hardening on mechanical properties of Al Mg Si alloy. The plastic deformation was provided by equal channel angular pressing (ECAP). It is found the ultimate and yield strength values are improved by two to three times. Aging after ECAP increased the ductility of the material [xiv]. Sever plastic deformations is the application of the methods that generate solid nanomaterials. To achieve large deformations that considerably exceeds the conventional values, special deformation techniques are used. Recently, the best common method used is the technque of equal channel angular extrusion [xv].

Reference [xvi] studied the work hardening and aging effect on 7xxx Al alloy. It is found that many parameters effect the hardening behavior e.g. partical distribution and their size, alloying elements and dislocation density in solid solution.

Reference [xvii] investigated the influence of the strain rate, texture and temper on the performance of an extruded AA7030 aluminium alloy by uniaxial tensile tests. The results reveals that the texture has a strong influence on ductility and plastic flow. However, its effect on ultimate strength, yield strength, and strain-hardening capability is low. Strain rates do not have too much influence on the yield strength and plastic flow. Whereas the strain-hardening and ultimate strength decrease expressively with increasing strain rate and ductility increases. The temper settings strongly influence the strain-hardening capability, ultimate and yield strengths, while their effect on plastic flow is partial. Reference [xviii] discussed that Cold working is suitable for parts with fine geometrical tolerances, smooth surface finish, good concentricity, and for net shape products. However, an increasing need for manufacturing components at a lower cost requires more cost-effective production processes. Forming in warm state is an alternative process that has the advantages of producing complex geometrical profiles in less operation steps as compared to cold forming.

An interaction exists between natural aging and pre-straining which decreases the material properties in the form of flow stress. Therefore, it is necessary to consider the collective effect of aging and plastic deformation in order to predict the mechanical properties with a reasonable accuracy. References [xix-xx] investigated that cold expansion technique is more efficient that produces more even compressive residual stress profile through the hole depth. Therefore, the temperature changes may be not as much of beneficial. It is thought that the higher temperature allows any irregular residual stresses along hole edge and through its depth in order to diffuse a small amount and vary towards the uniform compressive stress profile thus increases resistance to fatigue.

Aim of present work was to improve the mechanical properties, particularly hardness by different age hardening treatments. (T4, T6,and T8). The main objective was to study the effect of rolling on the hardness of the artificially aged alloy in a T8 heat treatment procedure and compare it with the hardness of the alloy in as-cast,artificially aged and naturally aged conditions.

II Material and Experimental Techniques

As-cast 2014 Al alloy used in the present work. Chemical composition is given in the Table 1.

TABLE I
CHEMICAL COMPOSITION OF 2014 ALUMINIUM ALLOY (WT%)

	Cu	Mg	Mn	Fe	Si	Zn	Al
Wt %	4.5	1.40	0.62	0.18	0.10	0.1	Balance

The as-cast alloy was in the form of 20mm diameter and 6 inch long bars. A slice of 200mm x 200mm was cut from the bar material and its initial hardness was measured. All the bars were homogenized by solution treatment in a Muffle type furnace at 502C° for 2 hours and then quenched in water for 4 to 5 minutes at room temperature. One bar was cut into three pieces of 200mm x 200mm size. The hardness of one sample was measured after homogenization and remaining two were artificially aged at 180C° and 232C° for 1 hour and then allowed to cool down at room temperature and then their hardness was measured. The remaining five bars were subjected to cold rolling in a STANAT rolling mill. The bars were deformed to different percentages. Three set of samples of 200mm x 200mm were cut from each deformed to a given percentage. Hardness of one set was measured before aging mechanism. Remaining two sets were artificially aged at 180C° and 232C° for 1 hour and then allowed to cool down to room temperature. Finally the hardness of these deformed samples was measured. The hardness values of heat treated samples were determined by using Vicker's hardness testing machine.

III Results and Discussion

The hardness testing results of as-cast and solution treated, quenched and naturally aged samples (T4 process) are given in Table II, and hardness values of solution treated, quenched and artificially aged samples (T6 process) are given in Table III. Solution treatment temperature (502C°) and time (2 hours) were the same for the two processes. It may be seen from These results that the hardness of the naturally aged sample increased to 113HV from the as-cast value of 85HV. The hardness of the sample increased further to

136HV and 145HV when artificially aged for one hour at 180C° and 232C° respectively.

TABLE II
VICKER'S HARDNESS OF SOLUTION TREATED SAMPLES

Solution treatment		Vicker's Hardness
Temperature (C°)	Time (h)	(HV)
As-Cast	--------	85
502C°	2 hour	113

TABLE III
VICKER'S HARDNESS OF SOLUTION TREATED AND AGED SAMPLES

Solution Treatment		Aging	Vicker's Hardness	
Temperature	Time	(HV)	Time	Temperature
136	1h	180C°	2h	502C°
145	1h	232C°	2h	502C°

TABLE IV
VICKER'S HARDNESS OF SOLUTION TREATED, COLD ROLLED AND ARTIFICIALLY AGED SAMPLES

Solution Treatment		% rolling	Vicker's Hardness		
Temp. (C°)	Time (h)	After solution treatment & quenching	Before aging (HV)	After aging at 180C° for 1 h (HV)	After aging at 232C° for 1 h (HV)
502	2	18	152.1	156.2	157.8
502	2	22	154.6	169.0	169.0
502	2	26	157.4	176.5	176.8
502	2	44	164.7	188.7	179.0
502	2	48	176.2	191.6	185.6

The hardness testing results of the samples which were subjected to T8 treatment i.e, solution treatment, quenching, cold rolling and artificial aging are included in Table IV. The solution treated and quenched samples were immediately cold rolled to different percentage. These were 18%, 22%, 26%, 44% and 48%. It may be seen from the data that after rolling, the hardness of the samples have significantly increased as compared to as-cast, naturally aged and artificially aged samples reaching a maximum value of 176.2HV (corresponding to maximum deformation of 48%). The results also show a continuous increase in hardness of the samples with the increase in the amount of deformation, as expressed graphically in Fig. 1. It may also be seen that even the smallest amount of plastic deformation increases a hardness of 152HV in the as-cast, solution treated and subsequently quenched specimen.

All the cold rolled specimens were aged for one hour at 180C° and 232C°. The hardness testing results, are given in Table IV and are expressed graphically in Figures 2 and 3. These results show a further increase in hardness of the cold rolled samples. The observed increase in hardness was found to be more at the aging temperature of 180C° then 232C° respectively. Therefore, the maximum hardness value obtained for the 2014 Al alloy correspond to those samples which were solution treated at 502C° for 2 hours, water quenched, cold rolled to 44% and 48% reduction in dimensions and then aged at 180C° for one hour. The maximum hardness values obtained were 188.7HV and 191.6HV corresponding to 44% and 48% reduction in dimensions respectively by cold rolling.

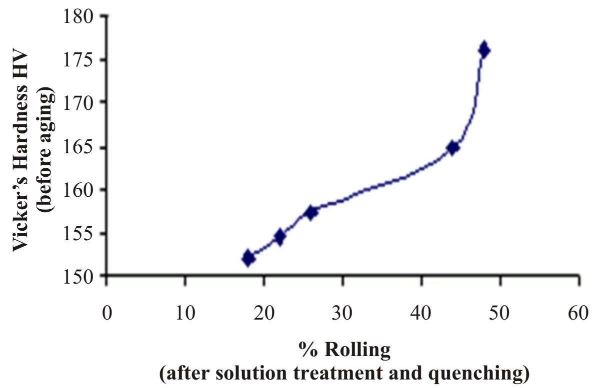

Fig. 1. %Rolling Vs Vicker's hardness

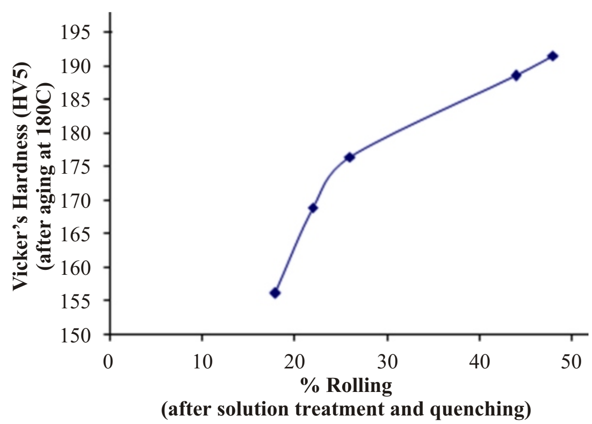

Fig. 2. % Rolling Vs Vicker's hardness.

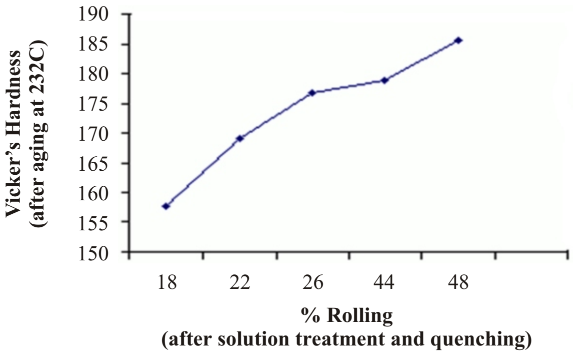

Fig. 3. % Rolling Vs Vicker's hardness

In a previous work on the same alloy [ii] reported an increase in hardness of the alloy by using T6 heat treatment conditions. The Al 2014 alloy was shown to exhibit a maximum increase in hardness from a as-cast value of 71.5HV to 148.8HV during an aging treatment carried out at 190C° for 7 hours. In present work, the maximum hardness values obtained were 137HV and 145HV at aging temperatures of 180C° and 232C° respectively in a similar aging treatment but the aging time selected was only one hour at both the temperatures as compared to 7 hours. Also, increase in hardness of the as-cast material 85HV to 137HV and 145HV was reasonably high while using a very short aging time of one hour. These values then increased even further using T8 heat treatment using the same short aging time of one hour, as described above.

CONCLUSIONS

Following conclusions may be drawn from above work on Al 2014 alloy

1. The hardness of the as-cast alloy increased from 85HV to 113HV when it was solution treated at 502C°, quenched and naturally aged (T4 treatment).
2. The hardness of the as-cast alloy increased from 85HV to 136HV and 145HV when solution treated at 502C°, quenched and artificially aged for one hour at 180C° and 232C° respectively (T6 treatment).
3. The hardness of the as-cast alloy was significantly increased when the alloy was subjected to various degrees of cold work after solution treatment at 502C° followed by water quenching. The maximum hardness obtained was 176HV corresponding to the maximum deformation of 48%.
4. Artificial aging of the solution treated, quenched and cold rolled alloy showed a higher increase in the hardness at 180C° than 232C°.
5. Maximum hardness values of solution treated, quenched and cold rolled alloy were found to be 188.7HV and 191.6HV corresponding to 44% and 48% cold deformation respectively and an aging temperature of 180C° for one hour's aging time.
6. Maximum hardness obtained in the alloy after solution treatment, cold working and aging at 232C° for one hour was found to be 185.6HV.
7. Increase in the hardness of the alloy during aging at both temperatures (180C° and 232C°) corresponding to increase in degree of cold work after solution treatment and quenching.

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