Indian J.Sci.Res. 17(2): 74-76, 2017

ISSN: 0976-2876 (Print)
ISSN: 2250-0138(Online)

# PREDICTION OF WEAR CHARACTERISTICS OF SEVERE PLASTICALLY DEFORMED Al2024

[1]Ajaya Bharti, [2]Brij Kishor, [3]Gourav Verma, [4]Rajneesh Gautam
[1,2,3,4]Department of Applied Mechanics, Motilal Nehru National Institute of Technology Allahabad

***Abstract-*** The light weight structures of Aluminium alloys are still widely used in weight sensitive products like aircraft, bicycles, boats, and automobiles, etc. The components fabricated from Aluminium alloys are desired to perform against the mechanical loads, cyclic loads, thermal stresses, creep loads, Wear loads and other environmental factors such as corrosive atmosphere or acidic atmosphere etc. In this present work, the Aluminium Alloy Al2024 was chosen because of its high strength and wide use in automobile and aerospace industry. In order to enhance the strength as well as wear performance the Al2024 was subjected to one of the severe plastic deformation technique i.e. rolling at room temperature as well as liquid nitrogen temperature. Through hardness test, it has been found that the Hardness is increasing with the compromise of ductility. Similarly, it has been found through reciprocating wear test that the wear resistance is increasing after rolling at room temperature as compared to solution- treated, however less than rolled at liquid nitrogen temperature.

***Keywords*** - Al2024, Ultrafine Grain, Cryorolling, Hardness, Wear

## I. Introduction

It has been reported that the plastic deformation of the metals and alloys provides the microstructural changes which leads to improve the mechanical properties [1-7]. In 1970, Dr. Segal was first researcher who worked upon the metals and alloys to convert the coarse grain in to fine grain material by the Severe Plastic Deformation (SPD) resulting better mechanical strength as well as better hardness and wear resistance [8-15]. Later, many of the researchers suggested and adopted different SPD techniques to achieve fine or ultrafine grain metals and alloys. Due to SPD processes, strength of material improves and it can be better understood by the Hall-Petch equation [1]. In the present work, cryorolling i.e. rolling at liquid-nitrogen-temperature; process was selected to deform the specimens to convert coarse grain materials into ultra-fine grain. After deformation the material, a comparative studied was made in terms of the microstructure, mechanical properties and wear resistance.

## II. Experimental Procedure

To start the experiments, the Al2024 was procured in the form of sheet having 5 mm thickness. For verification of the chemical composition, a chemical test was conducted at ELCA Laboratories, Thane, Mumbai, India and the test report is given in Table 1.

Table1. Chemical composition of the Al2024

| Element | Mg | Si | Cu | Fe | Cr | Zn | Ti | Mn | Al |
|---|---|---|---|---|---|---|---|---|---|
| Weight % | 1.2-1.8 | 1.2-1.8 | 3.4-4.9 | 0.5 | 0.1 | 0.25 | 0.15 | 0.3-0.9 | Balance |

Before start of rolling process of the Al2024, the strips of dimensions 5 mm x 35 mm x 100 mm were solution treated at 510 °C for two hours to nullify any previous effects. After solution treatment, strips were divided in to three groups. The first group of strips called as solution-treated (ST) was kept for microstructural test, mechanical test and wear study. The second group of strips was subjected to rolling up to 40% reduction at room temperature called as room-temperature-rolled (RTR) material. The third group strips were dipped for 10 minutes in to liquid nitrogen and then subjected to rolling up to 40% reduction called as cryorolled (CR).

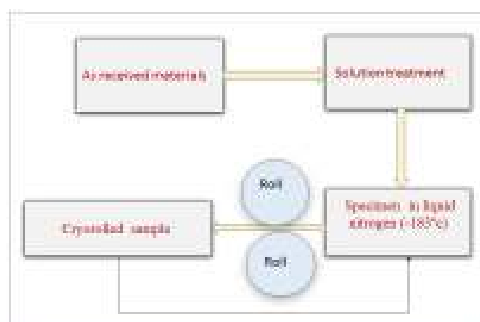


Figure1. Schematic diagram for cryorolling process

In order to investigate the effect of processing on the microstructure, the solution treated and rolled Al2024 were grounded with SiC paper and then polished with the Alumina powder. Further, the samples were etched by Keller reagent (2.5% $HNO_3$ + 1% HF + 95% $H_2O$) and put under the Microscope. According to ASTM E384 the Micro-vickers hardness tests were performed for all the three type of samples. During hardness test, the 5 gram load was applied with the indentation of 20μm and 10 second

[1]Corresponding Author

was given as dwell time. To see the effect of rolling at room temperature as well as liquid nitrogen temperature on the wear resistance, wear tests were performed involving the flat specimen and a spherically ended specimen (ball specimen) which slides against the flat specimen. In this, the load is applied vertically downward through the ball specimen against the horizontally mounted flat specimen. This test method involves reciprocating sliding where changes in the sliding velocity and direction of motion occurs during the test. However, constant velocity conditions are not maintained. The wear test conditions are given in Table 2.

Table 2. Parameters to perform wear Test

| Ball radius | Normal force | Stroke length | Oscillating frequency |
|---|---|---|---|
| 5 mm | 3-10 N | 100µm | 5.0 Hz |
| **Test duration** | **Ambient temperature** | **Relative humidity** | **Specimen size** |
| 37 min | 22 ± 3°C | 40 to 60 % | 15×15mm |

## III. Experimental Procedure

### A. Microstructure Examination

Fig. 2(b) and 2(c) are clearly depicting the effect of rolling on the grain size, elongation and orientation of the grain, formation of secondary phases as compared to solution treated material shown as Fig. 2(a). However, the much grain size has been reduced in case of cryo-rolling as compared to room-temperature rolling due to suppression of the dynamic recovery.

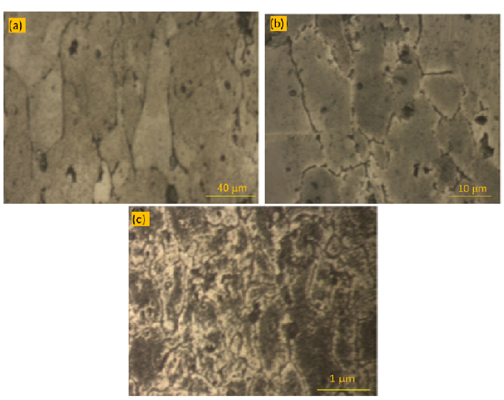


Figure2. Optical micrographs of (a) ST (b) RTR (c) CR at 100x showing the variation of Grain size

### B. Hardness analysis

In Fig. 3, the data obtained from Vicker's hardness tests has been plotted. It can be observed that the rolling at liquid nitrogen temperature (CR) i.e. cryorolling offers more resistance to plastic deformation as compared to room temperature rolled (RTR) and solution treated specimen (ST). It can be attributed towards the loss of ductility in lieu of hardness due to increase in the grain boundary density.

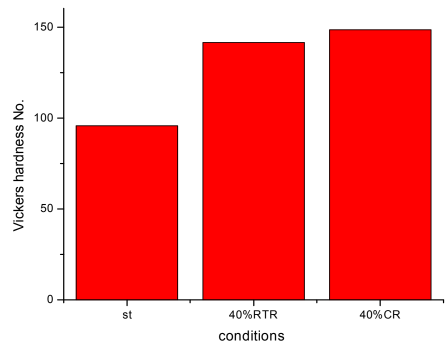


Figure3. Variation of Hardness before and after rolling at different temperature

### C. Wear Analysis

The critical portion (i.e. mostly damaged region) of damage is much bigger because of most superficial layer are removed and Formation of smearing(spot), crack and shearing zone is due to adhesive transfer of material, which enhanced wear volume under particular condition. Table 3 showes the dissipation energy, wear volume, specific wear rate and COF. The detailed analysis of wear characteristics are shown in the Table 3. The dissipation energy at 3 N loads was very less in cryorolled as compared to room temperature rolled and solution treated, as the load increases the dissipation energy was less in case of cryorolled as compare to room temperature rolled and solution treated.

Table3. Type of specimens, load and wear test results

| Type of Specimen | Dissipation Energy ($\times 10^{-4}$ Joule) | Wear Volume ($\times 10^{-3}$ $mm^3$) | Specific wear rate ($\times 10^{6}$ $mm^3$ /Nm) | COF |
|---|---|---|---|---|
| **ST-3** | 3.2244 | 152 | 50.660 | 0.52 |
| **ST-5** | 3.1226 | 502 | 100.400 | 0.38 |
| **ST-7** | 4.2346 | 580 | 82.857 | 0.34 |
| **ST-10** | 6.9582 | 2393 | 239.300 | 0.26 |
| **RTR-3** | 3.6357 | 209 | 69.660 | 0.58 |
| **RTR-5** | 3.9021 | 303 | 60.600 | 0.47 |
| **RTR-7** | 5.1768 | 495 | 7071.000 | 0.43 |
| **RTR-10** | 5.9808 | 4374 | 437.400 | 0.36 |
| **CR-3** | 2.8463 | 343 | 114.330 | 0.49 |
| **CR-5** | 2.944 | 974 | 194.8 | 0.42 |
| **CR-7** | 5.3478 | 1209 | 172.71 | 0.32 |
| **CR-10** | 5.4092 | 3964 | 396.4 | 0.22 |

Similarly it can be observed that the coefficient of friction (COF) was very less in case of cryorolled as compared to solution treated and room temperature rolled at lower load, as load increases coefficient of friction also decreases in a similar manner in cryorolled, room temperature rolled and solution treated. It can also be seen that specific wear rate in solution treated Al2024 at 3 N was less as compared to cryorolled and room temperature rolled, as load increases its behavior was changed and specific wear rate at cryorolled obtained less as compared to room temperature rolled. The significant increase in the wear resistance in case of cryorolled material was attributed to increase in the surface hardness due to reduction in the grain size, formation of dislocation cell, increase in the dislocation density and grain boundary area.

## IV. Conclusions

From the above mentioned experiments and results it was concluded that the rolling at lower temperature (Liquid Nitrogen Temperature) rather than at room temeperature i.e. around 30 $^{0}$C is more effective to reduce the grain size and other microstructural characteristics which enhances the hardness as well wear resistance in the metals and alloys.

## References

[1] RZ Valiev, AV Korznikov, RR Mulyukov (1993) Structure and Properties of Ultrafine-grained Materials Produced by Severe Plastic Deformation. MaterialsScience and Engineering A 168(2):141–148.

[2] RZ Valiev, RK Islamgaliev, IV Alexandrov (2000) Bulk Nanostructured Materials from Severe Plastic Deformation. Progress in Materials Science 45(2):103–189.

[3] A Azushima (2003) Trend of Ultrafine grained steel. Proceedings of the 245th Symposium on Technology of Plasticity, 225, 53–60. (in Japanese).

[4] N Tsuji, Y Saito, SH Lee, Y Minamino (2003) ARB (accumulative roll-bonding) and Other New Techniques to Produce Bulk Ultrafine Grained Materials. Advanced Engineering Materials 5(5):338–344.

[5] A Rosochowski, L Olejnik, M Richert (2004) Metal Forming Technology for Producing Bulk Nanostructured Metals. Steel Grips 2:35–44.

[6] A Rosochowski (2005) Processing Metals by Severe Plastic Deformation. Solid State Phenomena 101–102:13–22.

[7] Z Horita, (Ed.) (2005), Nanomaterials by Severe Plastic Deformation. Materials Science Forum, pp. 503–504.

[8] [1] Hashimoto M, Tanaka T, Inoue T, Yamashita M, Kurahashi R, Terakado R. Development of cold rolling mill rolls of high speed steel type by using continuous pouring process for cladding. ISIJ Int 2002;42:982-9.

[9] Choi JW, Chang SK. Effects of molybdenum and copper additions on microstructure of high chromium cast iron rolls. ISIJ Int 1992; 32: 1170-6,

[10] Morales J, Sandoval I. Influence of process parameters on friction coefficient of high-chromium rolls. AISE Steel Technol 1999; 76: 46–8.

[11] Pellizzari M, Cescato D, Flora MGD. Hot friction and wear behaviour of high speed steel and high chromium iron for rolls. Wear 2009; 267: 467-75.

[12] Tang, XH, Chung, R, Pang, C J, Li, DY, Hinckley B, Dolman K. Microstructure of high (45wt.%) chromium cast irons and their resistances to wear and corrosion, Wear 2011; 271:1426-31.

[13] Phan HT, Tieu AK, Zhu H, Kosasih B, Zhu Q, Grima A, Ta TD. A study of abrasive wear on high speed steel surface in hot rolling by Discrete Element Method Original. Tribol Int 2017;110:66-76.

[14] Li X, Du Z, Fu H, Feng Z, Zhao H. Experimental investigation on heat treatment of a high-speed steel for hot rolling roll mill. Materialwiss Werkst 2010; 41:170-6.

[15] Guo J, Liu LG, Sun YL, Li Q, Ren XJ, Yang QX. Parameter Optimization During Forging Process of a Novel High-Speed-Steel Cold Work Roll. J Mater Eng Perform 2016;25:188-98.