To Study about the behaviour of Mechanical Properties of the Material in Cryo-rolling process: A Review Approach

Mr. Shivkumar Panjabi - P.G.Student, Department of Mechanical Engineering(CAD/CAM), SCET, Kalol, Gujarat Technological University, Ahmedabad, India.
Email: panjabi.shiva@gmail.com

Mr. Jigar Paghadal - Assistant Professor, Department of Mechanical Engineering ,GIT, Gandhinagar, Gujarat Technological University, Ahmedabad, India.
Email: jigarpaghadal@gmail.com

Abstract: The various types of metal forming process are done on the materials to convert it into a desired geometry. In metalworking, rolling is a metal forming process in which metal stock is passed through one or more pairs of rolls to reduce the thickness and to make the uniform thickness. In now days we are generally dealing with the hot rolling and cold rolling which are performed above and below the recrystallization temperature. In recent days, the new development will focus on using the cryo-rolling process. Cryo-rolling is carried under cryogenic temperature. Cryogenic temperatures are defined by the Cryogenic Society of America as being temperatures below 120K (-244°F, -153°C). The main focus and deal with the cryo-rolling is it with improve the strength and hardness of the materials. By using the cryo-rolling the grain size of the material will be improve. In today competitive world market focusing on improve the material properties. Cryogenic processing makes changes to the crystal structure of materials. The major results of these changes are to enhance the abrasion resistance and fatigue resistance of the materials.

Key Words: Cryo-rolling, Recrystallization , Liquid Nitrogen , Ductility , Toughness , Strength.

Introduction:

Forming or metal forming, is the metalworking process of fashioning metal parts and objects through mechanical deformation; the work piece is reshaped without adding or removing material, and its mass remains unchanged.

Primary Metal Forming Processes

- Rolling
- Forging
- Extrusion
- Tube and wire drawing
- Deep drawing[1]

Rolling is the process of reducing the thickness or changing the cross-sectional area of the work piece by means of rolling mills.Rolling is classified according to the temperature of the metal rolled.Hot rolling is a metalworking process that occurs above the recrystallization temperature of the material**.**Cold rolling occurs with the metal below its recrystallization temperature (usually at room temperature).Warm is combination of both hot rolling and cold rolling. Its temperature lies in between hot rolling temperature and cold rolling temperature. Cryo-rolling is a potential technique to improve a strength and hardness of the material. It is a very effective and reliable process to get desired mechanical properties. In Cryo-rolling we dipped the material in liquid nitrogen (-190°c) and hold it for a few minutes or (depends on the geometry of materials) and then doing a rolling process.

Advantages of Cryo-rolling:

- By Cryo-rolling we can achieve an ultra-fine grain structure which improves a strength, ductility and micro-structure as well compared to cold rolling process.
- Handling of the material is easy in cryo-rolling compared to hot rolling process.

- If subsequently we are doing a annealing process after cryo-rolling then we can get a desirable ductility.
- Cryo-rolling requires a less plastic deformation compared to sever plastic deformation process. From Sever plastic deformation process, we can also achieve a ultra fine grain structure, but it require a large plastic deformation.

Disadvantages of Cryo-Rolling:

- By doing only cryo-rolling, we cannot get a proper ductility. Subsequent annealing process is requiring, but it is a preferable technique because after annealing process achieved.[2]

Literature Review:

1 In 2011 P.Aditya Rama Kamalnath & Apu Sarakar et al have discussed about tensile behavior of cryorolled zircaloy-2. It is mainly used in nuclear technology, as cladding of fuel rods in nuclear reactors, especially water reactors (BWRs). Hence high strength of Zircaloy-2 is of prime importance. For this analysis, four samples with various degrees of cryorolling (Annealed sample, 20%, 50% and 70% cryo rolled samples) are taken and tensile tests are conducted on these samples. The obtained results are analyzed and the optimum degree of cryorolling of Zircaloy-2 is obtained. The cryorolling improved the mechanical properties of the material as the dislocations are entangled near the grain boundaries and also due to decrease in the grain size. The microstructure of the sample is analyzed by optical microscope, before and after cryorolling and the grain structure analysis is done. [3]

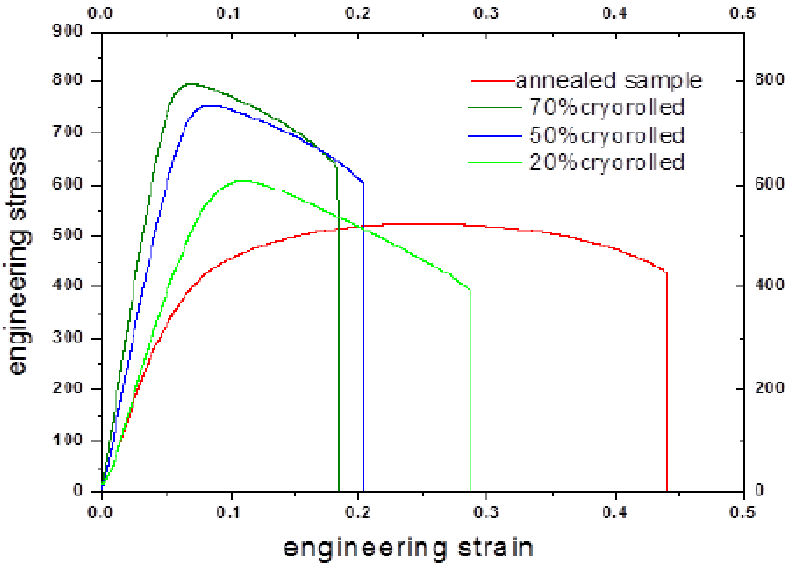

Fig. 1 % of thickness reduction

2 In 2011 P.Das, R.Jayganthan, T.Chowdhury, I.V.Singh et al talked about Improvement of fracture toughness of 7075 Al alloy by cryorolling process. The effects of cryorolling (Rolling at liquid nitrogen temperature) and optimum heat treatment (short annealing + ageing) on fracture toughness of 7075 Al alloy are reported in the present work. The Al 7075 alloy was rolled for different thickness reductions (40% and 70%) at cryogenic temperature and its mechanical, fracture toughness properties were studied. The micro structural characterization of the alloy was carried out by using Optical microscopy and Field emission scanning electron microscopy (FESEM). The cryo-rolled Al alloy after 70% thickness reduction exhibits ultrafine grain structure as observed from its FESEM micrographs. It is observed that the yield strength and fracture toughness of the CR material with 70% thickness reduction have increased by 108% and 73% respectively, compared to the starting material. The CR 7075 Al alloy shows improved fracture toughness and tensile strength due to high dislocation density, grain refinement, and ultrafine-grain (UFG) formation by multiple cryorolling passes. The CR samples were subjected to short annealing for 5 min at 190 °C, 170 °C and 150 °C followed by ageing at 160 °C, 140 °C and 120 °C for both 40% and 70% reduced samples. The combined effect of short annealing and ageing improves the fracture toughness, tensile strength, and ductility of cryorolled samples, which is due to precipitation hardening and sub grain coarsening mechanism respectively. The scanning electron microscopy (SEM) fractographs of the Al 7075 alloy samples reveals that starting bulk Al alloy specimens is fractured in a total ductile manner, consisting of well-developed dimples over the entire surface and dimple size got decreased continuously for cryorolled specimens at different percentage of thickness reduction (40% and 70%) as observed.[4]

3 In 2006 T.Shanmugasundaram, B.S. Murty, V.Subramanya Sarma et al have experiment on Al-Cu alloy by cryo-rolling to development of high strength ultrafine grain. The microstructure and mechanical properties of a precipitation hardening Al–Cu (2219) alloy subjected to cryorolling, low temperature annealing and ageing treatments are done. Under optimal processing conditions, ultrafine grained microstructure with improved tensile strength (540 MPa) and good ductility (11% tensile elongation) was obtained. Cryorolling of 2219 Al alloy (thickness reduction of 85%and true strain of 2) followed by annealing at 175 °C for3 min and ageing at 125 °C for 8 h resulted in UFG microstructure (grain size of 500 nm to 1 lm) with improved mechanical properties (YS of 485 MPa and UTS of 540 MPa with a tensile ductility of 11%). [5]

4 In 2012 Yusaku Takagawa, Yukinaru Tsujiuchi, Chihoro Watanabe, Ryoichi Monzen, Nobuhiro Tsuji et al have investigated Improvement in Mechanical Properties of a Cu2.0 mass%Ni0.5 mass%Si0.1 mass%Zr Alloy by Combining Both Accumulative Roll-Bonding and Cryo-Rolling with Aging. The enhancement in tensile properties of a Cu2.0 mass%Ni0.5 mass%Si0.1 mass%Zr alloy are attempted by combining both accumulative roll-bonding (ARB) and cryo-rolling with aging treatment. The grain sizes of the alloy pre-aged at 450°C and ARB-processed in six cycles (P-ARB) and of the alloy pre-aged at 450°C and cryo-rolled to a 90% reduction (P-90CR) are refined to about 0.1 and 0.2 μm, respectively. Both six cycles of ARB and 90% cryo-rolling, together with the presence of fine precipitates formed by presaging at 450°C, give significant grain refinement. The P 90CR alloy aged at 350°C exhibits a higher 0.2% proof stress of 830 MPa and a higher tensile strength of ·u = 900MPa than the P-ARB alloy aged at 375°C. The higher proof stress of the aged P-90CR alloy than the aged P-ARB alloy is ascribed to the higher dislocation density in the aged P-90CR alloy. The value of ·u = 900 MPa for the aged P-90CR alloy is larger than that of ·u μ 830MPa for conventional commercial Cu3.0 mass%Ni0.65 mass%Si system alloys. The value for the former alloy is nearly identical to μ 46% IACS for the latter alloys. [6]

5 In 2013 Hai-liang Yu , A. Kiet Tieu , Cheng Lu , Xiang-hua Liu, Ajit Godbole, Charlie Kong et al have discussed about asymmetric cryorolling and ageing treatment of Al-Mg-Si alloy sheets An asymmetric cryorolling technique was used to reduce the thickness of an Al-Mg-Si alloy sheet from 1.5 mm to 0.19 mm. The samples were subsequently aged for 48 h at 100 degrees Celsius. The hardness and tensile strength of both rolled and aged sheets increased with the number of passes up to the sixth pass, but the tensile stress decreased after the seventh pass. Investigation of the microstructure of the sheets showed that the grain size after seven passes was about 235 nm and revealed the presence of Fe-Cr-Mn-Si particles in the samples. The deformation of Fe-Cr-Mn-Si particles and sheet thickness affects the ductility when the sheet thickness is less than 0.4 mm, and the strength when the thickness is less than 0.2 mm. [7]

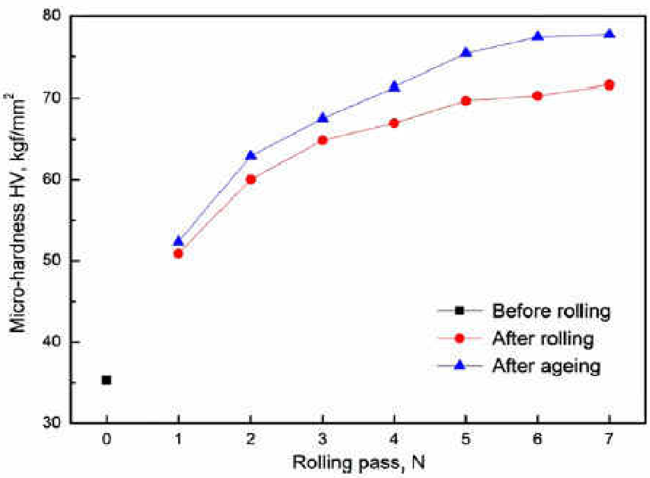

Fig.2. Micro-hardness of sample before rolling, after rolling and after ageing.

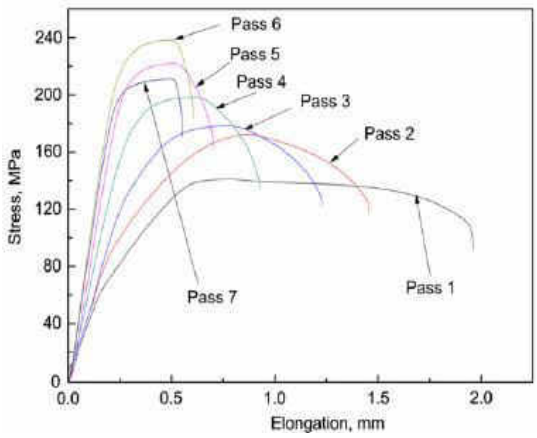

Fig. 3 Tensile curve for rolled sample

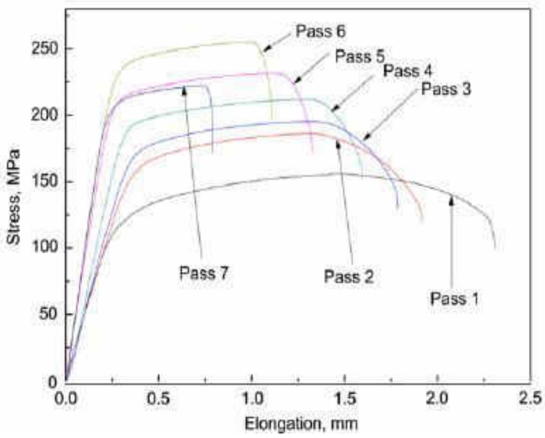

Fig.4 Tensile curve for aged sample

6 In 2013 Dharmendra Singh, P. Nageswara Rao, R. Jayaganthan et al have mentioned that Effect of deformation temperature on mechanical properties of ultrafine grained Al–Mg alloys processed by rolling. Aluminum–Magnesium (Al 5083) alloy was subjected to cryorolling (CR) and cryorolling followed by warm rolling (WR) in order to investigate the changes in mechanical behavior and microstructure evolution. Al alloy specimens were first cryorolled up to 50% thickness reduction followed with warm rolling at 100°C, 145°C, 175°C and 200°C till to achieve total 90% thickness reduction. The final microstructure of all conditions were analyzed and compared through transmission electron microscopy (TEM), Electron back scattered diffraction (EBSD), and X-ray diffraction (XRD) techniques to investigate the effect of WR deformation temperatures on mechanical properties. The mechanical behavior of the processed samples were evaluated through hardness and tensile tests performed at room temperature. An increase in yield strength (522 MPa), ultimate tensile strength (539 MPa) and ductility (6.8%) was observed in WR specimens at 175°C, hardness also increases to (146 HV) as compared to CR samples. These samples were annealed in temperature range from 150°C to 300°C to investigate their thermal stability. The CR samples exhibited severely deformed structure with high dislocation density network while cryorolled followed by warm rolled (WR) samples has shown formation of ultrafine grains associated with dynamic recovery. At elevated temperature of 200°C, WR samples showed decrease in strength accompanied with increase in elongation due to dominant dynamic recovery effect led to reduction in dislocation density. [8]

7 In 2008 Sushanta Kumar Panigrahi, R. Jayaganthan, Vivek Pancholi et al have showed that the effect of plastic deformation on mechanical and ageing characteristics of Al–Mg–Si alloy (Al 6063 alloy) subjected to cryogenic and room temperature rolling was investigated by employing hardness measurements, tensile tests, XRD analysis, and EBSD and TEM characterizations. The severe strain induced during plastic deformation of Al 6063 alloy produces ultrafine microstructures with improved strength and hardness. The ageing treatment of the severely deformed Al 6063 alloy has improved its strength and ductility significantly due to the precipitation hardening and grain coarsening mechanisms, respectively. The mechanical properties of cryorolled and room temperature rolled Al 6063 alloy were compared.

Table: 1 Different state condition of sample

Different treatments	Processing conditions
State 1	T4 treatment + CR
State 2	45 min at 520 °C + water quenched + CR
State 3	2h at 420 °C + Furnace cooled + CR
State 4	45 min at 520 °C + water quenched + RTR
State 5	2h at 420 °C + Furnace cooled + RTR

Cryorolled Al 6063 alloys (in states 2 and 3) exhibit a significantly higher value of Hardness, YS and UTS than that of the RT rolled materials (states 4 and 5) owing to the fact that cryogenic temperature can effectively suppress the dynamic recovery and builds up a higher dislocation density in the samples. A significant enhancement of the mechanical properties of solid solution treated CR Al alloys (state 2) was observed as compared to the CR Al alloys followed by annealing (state 3). The presence of high solute content in the matrix retards the dislocation annihilation and increases the retained dislocation densities, contributing to the enhancement in their strength. The initial hardness, YS and UTS of the Al 6063 alloys in state 1 are higher than that of the other states due to the presence of a small volume fraction of fine second phase (Mg2Si) particles. These fine particles were sheared and lost during severe deformation and hence the initially hard (state 1) materials lose its hardening mechanisms. The pre-CR solid solution treatment (state 2) combined with post-CR low temperature ageing of Al 6063 alloy show a remarkable improvement in mechanical properties as compared to the other states due to the combined effect of recovery, grain refinement, dislocation hardening, and precipitation hardening. All the plastically deformed Al 6063 alloys (states 1, 2 and 4) exhibit severely elongated grains along the rolling direction with lower grain boundary misorientation angles and high dislocation density. As compared to the other states, the solution treated materials processed by cryorolling (state 2) exhibits higher fraction of medium angle grain boundaries due to the intermetallic particles and higher amount of solutes in the solid solution. [9]

8 In 2009 P. N. Rao, S. K. Panigrahi and R. Jayaganthan et al have communicated Effect of annealing and aging treatment on mechanical properties of ultrafine grained Al 6061 alloy A comparative study of aging and a combined treatment of short annealing and aging on mechanical properties and microstructure of cryorolled (CR) Al 6061 alloy is investigated in the present work by using tensile tests, hardness tests, electron backscattered diffraction and transmission electron microscope. The pre-CR solid solution treatment combined with post-CR short annealing (200uC, 5 min) followed by aging treatment (100uC, 57 h) of the Al 6061 alloy showed an improved ductility and well defined ultrafine grain structure as compared to the samples subjected to pre-CR solid solution treatment followed by post-CR aging treatment (100uC, 60 hA substantial improvement in ductility without compromising the tensile strength (359.2 MPa) was observed for the CR Al 6061 alloy subjected post-CR SA (200uC, 5 min) followed by aging treatment (100uC, 57 h) than that of the similar samples subjected to post-CR aging treatment (100uC, 60 h) without annealing (ductility510 and tensile strength5360 MPa). The SA of CR samples relieves the internal stress and realigns the dislocations structures. The improvement of both strength and ductility in ultrafine grained Al 6061 alloy is due to the influence of dislocation strengthening, grain refinement, precipitation hardening and substructure coarsening. [10]

9 In 2012 P. Nageswara Rao, R. Jayaganthan et al have highlighted Effects of warm rolling and ageing after cryogenic rolling on mechanical properties and microstructure of Al 6061 alloy. The mechanical properties and micro structural evolution of Al 6061 alloy subjected to cryorolling and warm rolling have been investigated in the present work. The Al 6061 alloy was subjected to thickness reduction of 70% by cryorolling followed by thickness reduction of 20% by warm rolling. The cryorolled + warm rolled (CR + WR) samples were characterized by Electron back scattered diffraction (EBSD) technique, Differential scanning calorimeter (DSC), X-Ray diffraction (XRD) analysis and Transmission electron microscopy (TEM) technique to substantiate the role of deformation strain and temperature on their micro structural features and compared with cryorolled (CR) samples. The CR +WR samples showed a significant improvement in tensile strength (376 MPa) and partial improvement in ductility (5%) as measured from tensile testing. It is mainly due to the combined effect of partial grain refinement, solid solution strengthening, dislocation hardening, dynamic recovery, and dynamic ageing during cryorolling and warm rolling. The effect of ageing on CR +WR samples was investigated and the optimum ageing condition was found to be 45 h at 125 °C, which gives improved tensile strength of (406 MPa) and good tensile ductility (10%). The tensile strength of cryorolled + warm rolled + peak aged (CR +WR + PA) sample (406 MPa) was found to be 11.2% more than that of cryorolled + peak aged (CR + PA) sample (365 MPa). [11]

Conclusion :

From the literature survey of all the cryo-rolling experiments, the mechanical properties like ductility, hardness, toughness, tensile strength has been studied and compared with another material. Most common in all literatures material and alloys used for experiments are not under DBTT (Ductile-Brittle transition temperature) at lower temperature. It is used to check the mechanical properties of metal. It is also noticed that mechanical properties as well as surface morphology is also taken as a major criteria for crystal structures of that test sample of metals. These microstructures of any metal then checked in digital instruments like Scanning electron microscopes, Transmission electron microscopes, and X-ray diffractions etc. These microstructure and mechanical properties are then compared with cryo-rolling to get best out of it.

Acknowledgement:

We express my cavernous sense of obligation and gratitude to Mr. Govind Patel, Assistant Professor at SCET,KALOL and Mr. Divyarajsinh Rathod, Assistant Professor at Rai University, Ahmedabad for his genuine guidance and constant encouragement throughout this review work. Last but not the least I(Mr.Shivkumar Panjabi) am thankful to SCET,KALOL for providing me the opportunity to development of my career.

References:

1. Aditya Rama Kamalnath & Apu Sarakar (2011) Mechanical Properties of Cryorolled Al 7075 Alloy, DOI: 10.1007/s11661-010723-y, The Minerals, Metals & Materials Society and ASM International 2011. Tensile Behavior of Cryorolled Zircaloy-2. Global Journal of Researches in Engineering Volume XII Issue VIII Version I.
2. P.Das, R.Jaygantham, T.Chowdhury, I.V.Singh (2011) Improvement of Fracture Toughness (K1c) of 7075 Al Alloy by Cryorolling Process. Materials Science Forum Vol. 683 (2011) pp 81-94. Trans Tech Publications, Switzerland.
3. T.Shanmugasundaram, B.S. Murty, V.Subramanya Sarma (2005). Development of ultrafine grained high strength Al–Cu alloy by cryorolling Scripta Materialia 54 (2006) 2013–2017.
4. Yusaku Takagawa, Yukinaru Tsujiuchi, Chihoro Watanabe, Ryoichi Monzen, Nobuhiro Tsuji (2012) Improvement in Mechanical Properties of a Cu2.0 mass%Ni0.5 mass%Si0.1 mass%Zr Alloy by Combining Both Accumulative Roll-Bonding and Cryo-Rolling with Aging. Materials Transactions, Vol. 54, No. 1 (2013) pp. 1 to 8 2012 The Japan Institute of Metals.
5. Hai-liang Yu, A. Kiet Tieu, Cheng Lu, Xiang-hua Liu, Ajit Godbole, Charlie Kong (2013). Mechanical properties of Al-Mg-Si alloy sheets produced using asymmetric cryorolling and ageing treatment. Materials Science and Engineering A: Structural Materials: Properties, Microstructure and Processing, 568 212-218.
6. Dharmendra Singh, P. Nageswara Rao, R. Jayaganthan (2013) Effect of deformation temperature on mechanical properties of ultrafine grained Al–Mg alloys processed by rolling. Materials and Design 50 (2013) 646–655.
7. Sushanta Kumar Panigrahi, R. Jayaganthan, Vivek Pancholi (2008) Effect of plastic deformation conditions on micro structural characteristics and mechanical properties of Al 6063 alloy. Materials and Design 30 (2009) 1894–1901.
8. P. N. Rao, S. K. Panigrahi and R. Jayaganthan (2009) Effect of annealing and aging treatment on mechanical properties of ultrafine grained Al 6061 alloy, 2010 Institute of Materials, Minerals and Mining Published by Maney on behalf of the Institute. DOI 10.1179/174328409X443227.
9. P. Nageswara Rao, R. Jayaganthan (2012). Effects of warm rolling and ageing after cryogenic rolling on mechanical properties and microstructure of Al 6061 alloy Materials and Design 39 (2012) 226–233.

Websites:

Web link:http://paniit.iitd.ac.in/~pmpandey

Weblink:http://www.indiastudychannel.com/resources/146476-What-is-a-cryo-rolling-and comparision-with-other-rolling-process.aspx