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Research Article

The Tensile and Wear Property Enhancement of Al – Zn –Mg Alloys by Precipitation Hardening and Thermomechanical Treatments

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Abstract

Al – Zn-Mg alloys are precipitation hardenable and suitable to thermomechanical treatment. Well known performance characteristics, known fabrication costs, design flexibilities and established manufacturing methods are few of the reasons for the continued confidence in 7XXX series Aluminium alloys. These alloys are effectively used in aerospace industries due to high specific strength, formability and flexibility in property alteration. The small percentage addition of magnesium improves wettability and tensile properties. Precipitation hardening includes solutionising and aging as two basic steps in heat treatment. Solutionising improves formability by retaining high temperature FCC structure at room temperature as super saturated phase and aging allows the precipitation of solute rich intermetallics from super saturated phase. The property enhancement depends upon the temperature and time relationships. Thermomechanical treatment includes intentional deformation of the specimen as the intermediate step between the basic steps of precipitation hardening. Low temperature thermomechanical treatment is concentrated about cold or warm deformation of solution treated specimen before aging. Cold deformation increases lattice defects due to strain hardening. Increase in lattice defect enhances the Intermetallic precipitation rate and well distributed fine precipitates forms during aging. Tremendous improvement in hardness and toughness are seen compare to conventional precipitation hardening if the process is tailored accordingly. In view of this, six different Al – Zn alloys with out and with magnesium addition (1 & 3 wt. %) are analyzed. The cast alloys are homogenized before precipitation hardening and thermomechanical treatment. The hardness strength and wear resistance values are analyzed and compared with magnesium free Al – Zn alloys. Age hardening phenomena is accelerated due to the increased number of potential sites for precipitation in thermomechanical treatment. Higher peak hardness and lesser aging time are the characteristics of thermomechanically treated samples. For maximum hardness, optimum weight percentage of alloying elements is required. The peak aged specimen shows excellent combination of tensile and wear properties.

Keywords: *Al – Zn alloys, Thermomechanical, precipitation hardening, lattice defect, solutionising.*

1. Introduction

The properties of various aluminium alloys can be altered by age hardening heat treatment. The age hardening heat treatment can be classified into two processes, including solution heat treatment and artificial aging [De Sanctis M et al, 1991, Duan X, Hao et al, 1994, Lengsfeld P et al, 1995 and Li X. Z, Hansen et al, 1999]. This consists of heating the alloy to a temperature between 300 to 450^{0}C at which all the alloying elements are in solution. By heating the solution treated material to a temperature above room temperature and holding it there, the precipitation of intermetallics accelerates and the strength is further increased compared to natural aging and accompanied by a clear drop in ductility [Troeger L. P et al, 2000, Berg L. K et al, 2001, and Song R. G et al, 2001]. This is called ‘‘artificial aging’’, ‘‘age hardening’’ or just ‘‘aging’’ and is generally carried out at temperatures up to approximately 200^{0}C. Age hardening Al–Zn–Mg series alloys have been widely used as structural materials in the aerospace and automotive industries due to the attractive combined properties, such as low density, high strength, hardness, ductility and toughness. In recent years, aluminum alloys have attracted attention of many researchers, engineers and designers as promising structural materials for automotive industry or aerospace applications [Tangen Stian et al, 2002, Lee S. H et al, 2002, Robson J. D et al,2002, Chen S. P et al 2003 and Starink M. J et al, 2003]

Thermomechanical treatment (TMT) consists of deforming the metal between the solution treatment and the aging treatment in thermomechanical processing of precipitation hardenable alloys. Low temperature thermomechanical treatment (LTMT) is concerned about cold deformation of the metal. The effect of deformation

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*Corresponding author: **Gowri Shankar M. C** on precipitation kinetics has often been attributed to an increase of dislocation density, which increases the nucleation sites, for phase transformation and provides easy diffusion paths for precipitation-forming elements in the material, leading to accelerated precipitation process as compared with the undeformed alloy [Chen K. H et al, 2003, Dumont D et al, 2003 and Wang D et al, 2008]. It is also believed that the precipitation process can still be promoted even when the dislocations formed during deformation have been eliminated before the precipitation starts. Therefore, the effect of deformation on the precipitation cannot be explained from dislocation density considerations alone. Some experimental observations have suggested that deformation can cause the redistribution of the precipitate forming elements between the dislocation cell walls and the cell interiors. Thus segregation of the solute atoms to the potential nucleation sites may also contribute to precipitation kinetics and could provide an explanation for the observed acceleration of the precipitation process [E. Sjolender et al, 2010 and Norbert Ponweiser et al 2012].

It is clear that cold working enhances precipitation of strengthening phases, which has been put to good use for many years for achieving superior properties in various Al alloys and composites. This relationship between cold working and precipitation be used advantageously in tailoring the properties of these materials in order to overcome the specific problems.

2.0 Experimental details

2.1 Alloy preparation

Six types of Al alloys are cast in the laboratory. The table 2.1 shows the composition of the alloys.

Table 2.1: Composition of 6 types of alloys used in this study

Type	Chemical composition
A	Al – 10Zn
B	Al – 10Zn – 1Mg
C	Al – 10Zn – 3Mg
D	Al – 5Zn
E	Al – 5Zn – 1Mg
F	Al – 5Zn – 3Mg

The melt is poured into the metallic mould to get the dimension of casting as 60mm x 20mm x 100mm. The cast metal is cut into small test pieces of 25mm x 20mm x 10mm.

2.2 Homogenizing treatment

Specimens are heated isothermally for 12 hrs at 400^0C. To minimize the oxidation of the alloy, the fusible salt bath of $NaNO_2$ and KNO_3 is used. At such a high temperature the solute clusters are eliminated and homogeneous chemical composition is obtained.

2.3 Deformation to suitable initial size

During deformation to reduce the specimen thickness from 10mm to 2mm, severe strain hardening is observed and specimen used to fail during cold rolling. Intermediate annealing treatment of 2 hours at 350^0C was carried out to nullify the work hardening effect. Initial specimen thickness for 33% and 50% deformation is 3mm and 4mm respectively.

2.4 Conventional age hardening treatment

Specimens are first heated to 350^0C in salt bath and quenched in cold water. This solution treated samples are aged at 50^0C and 100^0C and hardness versus aging duration graphs are plotted for all six types of alloys

2.5 Thermomechanical treatment

All the specimens are cold rolled after solution treatment with 33 and 50% of deformation to reduce the thickness to 2mm. At the end, rolling is performed through several passes giving only a small amount of reduction in each pass without any intermediate annealing treatment. These strained samples are aged at 50^0C and 100^0C and hardness versus aging duration graphs are plotted.

2.6 Hardness measurement

All the treated and untreated specimens are subjected to Rockwell hardness test and the “B” scale hardness numbers are noted.

2.7 Tensile test

First, tensile specimens are prepared for the test. Size and shape of the specimens is shown in Figure 2.7.1. Tension test is carried out on laboratory UTM of 100KN capacity (made by INSTRON) at cross head speed of 5mm/minute. Engg stress versus Engg strain graphs are plotted. Yield strength is taken as 2% proof stress. Yield strength, UTS, %elongation is found for some selected specimens.

2.8 Wear test

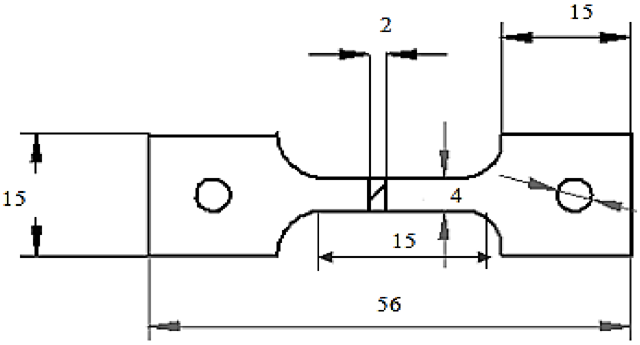

Figure 2.7.1 Overall dimension of a tensile specimen (all dimensions in mm)

The dry sliding wear behaviour is analyzed here. Before taking the reading, a trail run of 30mins is provided to all the specimens to develop a perfectly flat and smooth contact surface. The experiment is conducted on pin-on-disc apparatus for 1hr 15mins each on all specimens and the weight loss is noted at every 15mins run of the specimen. Shape and size of the specimen used for wear test is shown in Figure 2.8.1. Specimen is joined to steel shank by the adhesive. Calculation of the sliding distance in KM is shown below.

$$\text{Sliding speed in m/sec} = \frac{\pi DN}{60,000}$$

Where, D = diameter of wear track in mm (88mm)
T = test duration in seconds = 15mins
N = RPM of disc (200)
Sliding distance for 15mins is 3.317KM

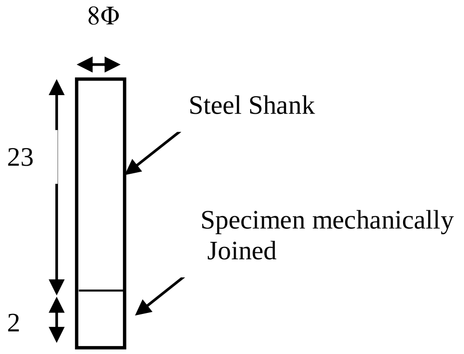

Fig 2.8.1 Wear testing specimen (all dimensions in mm)

3.0 Results & discussions

3.1 Hardness measurement

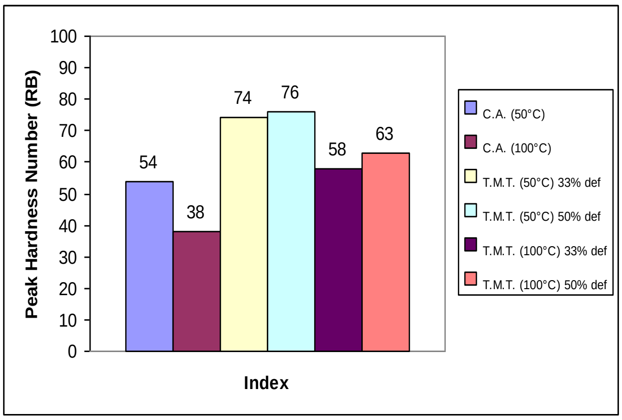

Fig 3.1.1 Variation of hardness with the aging duration

Figure 3.1.1 shows the hardness curves with the aging duration for "A" type alloy. Similarly graphs are drawn for all the other alloys and peak hardness values are noted. Peak hardness value increases with the increase in degree of deformation and decrease in aging temperature. In conventional aging, lower aging temperature increases the peak hardness value but with the longer aging duration. Increase in peak hardness value is due to the increase in the number of intermediate transition zones during the formation of intermetallic phases. Figures 3.1.2 to 3.1.7 show the peak hardness values of respective alloy with the modification in heat treatment. The increased hardness is observed in Al-5%Zn alloy group compare to Al-10%Zn alloy group. Also magnesium addition increases the response of alloy to TMT. The alloy Al-5Zn-3Mg shows the highest peak hardness values in the Al-Zn-Mg groups. An optimum number of optimum sized well distributed intermetallics in the matrix contribute a lot to the increased strength and hardness. Literature also indicated the presence of $MgZn_2$, $Mg_3Zn_3Al_2$ intermetallics in such alloy systems.

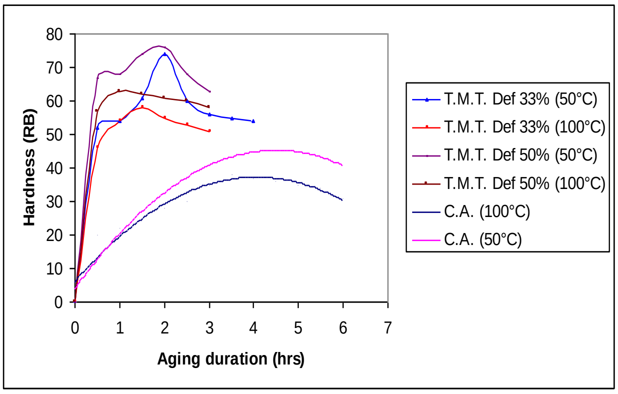

Fig 3.1.2 Variation of peak hardness of "A" type alloy with the modification in heat treatment

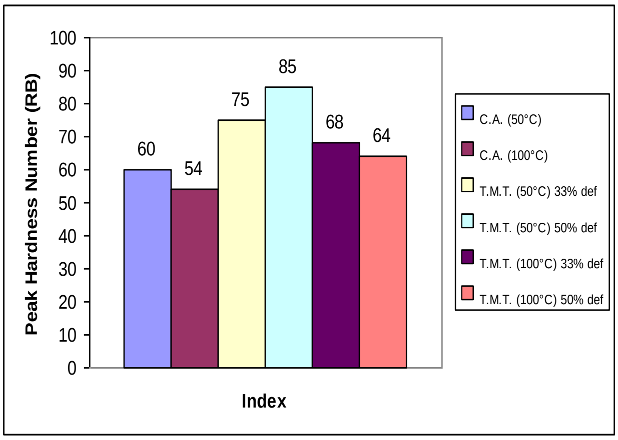

Fig 3.1.3 Variation of peak hardness of "B" type alloy with the modification in heat treatment

3.2 Tensile test

Figure 3.2.1 shows the yield strength variation of thermomechanically treated alloys. Figure 3.2.2 shows the UTS variation of thermomechanically treated alloys. All the tensile graphs show the increase in tensile values with the increase in degree of cold deformation. Al-5Zn-3Mg showed best results. This also supports the argument that fine, well distributed optimum number of particles is responsible to the increase in strength. Figure 3.2.3 shows the variation in ductility values with the thermomechanically treated alloys. Surprisingly the

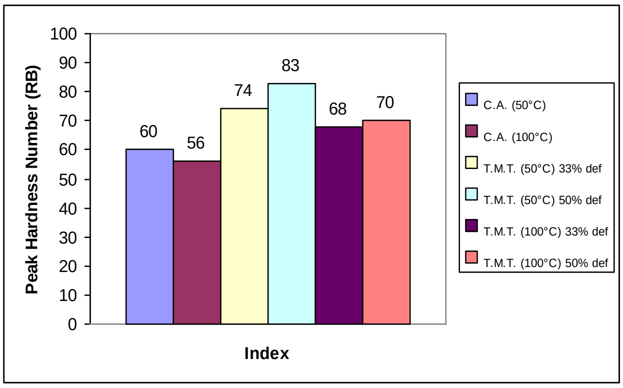

Fig 3.1.4 Variation of peak hardness of “C” type alloy with the modification in heat treatment

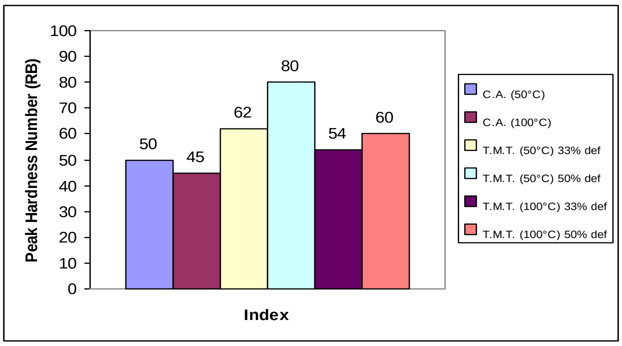

Fig 3.1.5 Variation of peak hardness of “D” type alloy with the modification in heat treatment

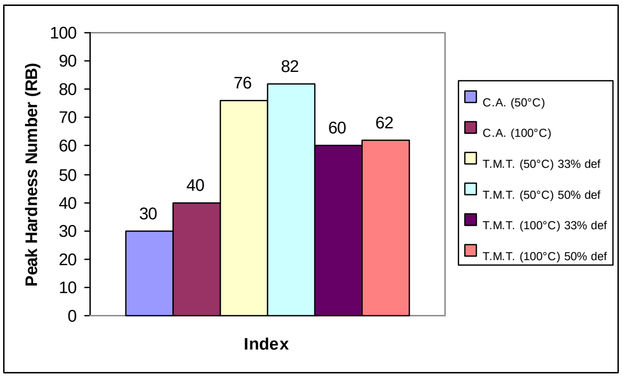

Fig 3.1.6 Variation of peak hardness of “E” type alloy with the modification in heat treatment

addition of 3Mg to Al-5Zn alloy shows an increase in ductility value inspite of an increase in strength and hardness values. So if the TMT is properly tailored in the Al alloy with an optimum number of Zn & Mg content, the ductility, hardness strength can be improved.

3.3 Wear test

Figures 3.3.1 to 3.3.6 show the cumulative wear versus sliding distance graphs for all the six types of alloys with different heat treatment conditions. Wear is generally the function of hardness. In all the cases, conventionally aged at 100^{0}C specimens show least resistance to wear. Thermomechanically treated specimen with high degree of deformation and aged at lower temperature showed higher wear resistance. All the specimens contribute higher wear resistance when thermomechanically treated with high degree of deformation, Al-5Zn-3Mg specimen emerged as highest wear resistance material in the group. As the hardness increases, the wear resistance of the specimen also increases. Increase in wear resistance and the mechanical properties is due to the combined effect of dislocations with the precipitating secondary phases (intermetallics).

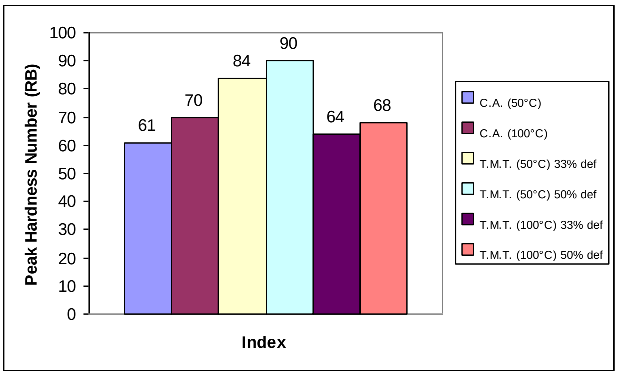

Fig 3.1.7 Variation of peak hardness of “F” type alloy with the modification in heat treatment

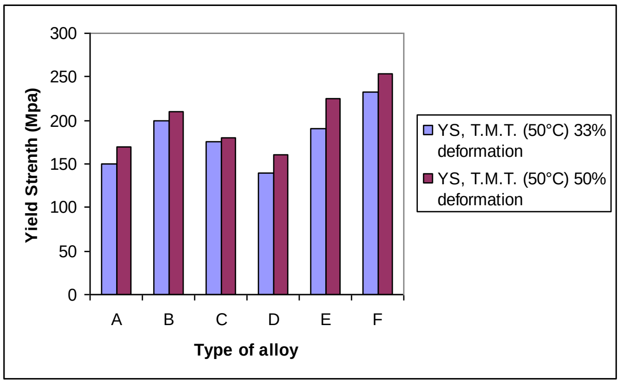

Fig 3.2.1 Yield strength variation of thermo mechanically treated alloys

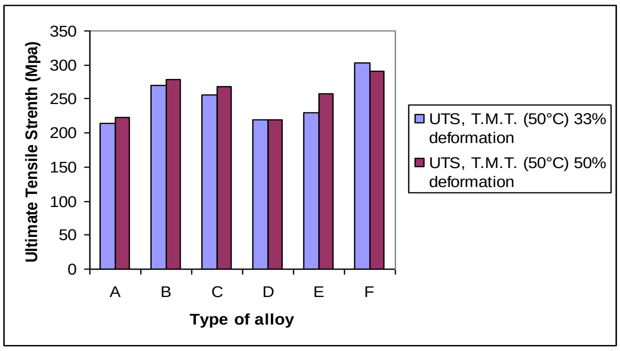

Fig 3.2.2 UTS variation of thermomechanically treated alloys

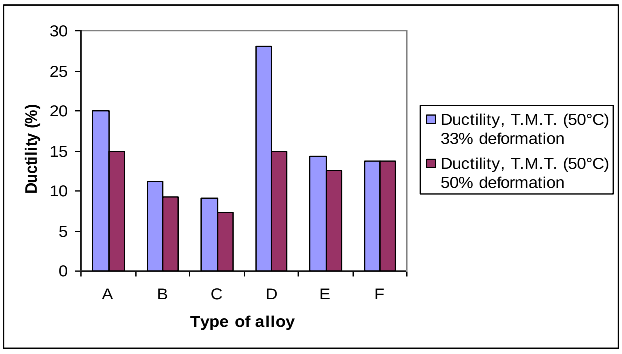

Fig 3.2.3 Variation in ductility with thermomechanically treated alloys

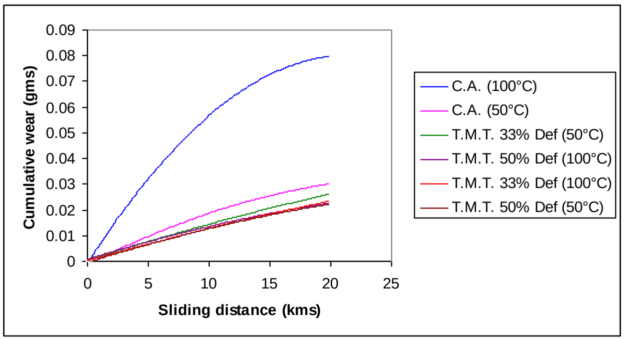

Fig 3.3.1 Cumulative wear versus sliding distance of "A" type alloy

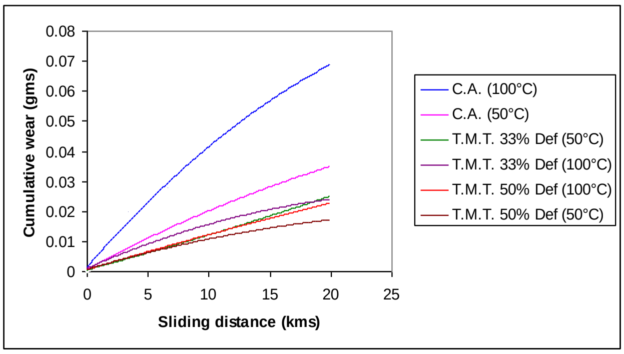

Fig 3.3.2 Cumulative wear versus sliding distance of "B" type alloy

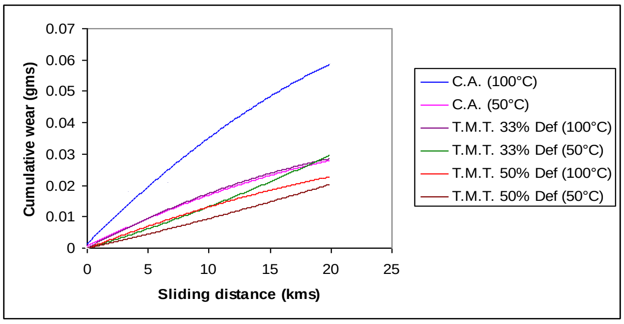

Fig 3.3.3 Cumulative wear versus sliding distance of "C" type alloy

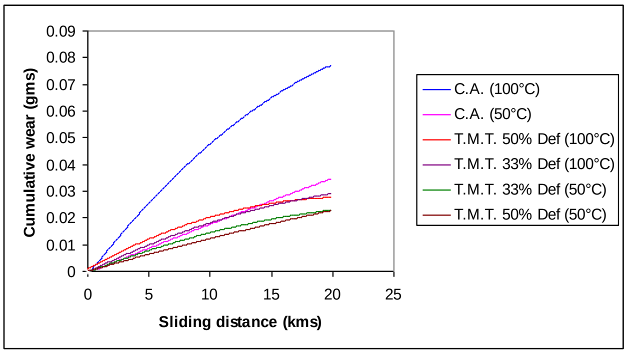

Fig 3.3.4 Cumulative wear versus sliding distance of "D" type alloy

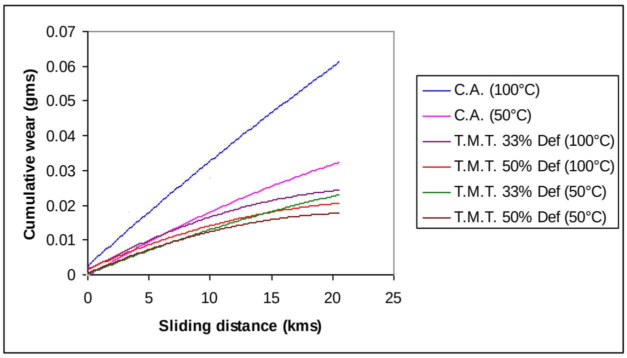

Fig 3.3.5 Cumulative wear versus sliding distance of "E" type alloy

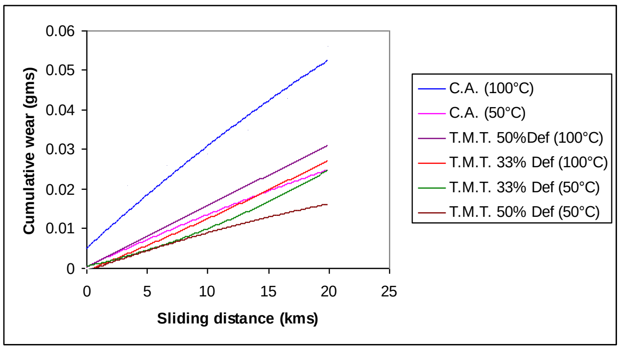

Fig 3.3.6 Cumulative wear versus sliding distance of "F" type alloy

4.0 Conclusions

- Lower aging temperature increases the peak hardness values with increased peak aging duration.
- Thermomechanically treated specimens show higher peak hardness values with decreased peak aging duration.
- In TMT, as the degree of cold deformation increases or aging temperature decreases, the peak hardness values increase.
- Yield strength and ultimate tensile strength are higher for thermomechanically treated specimen with higher degree of deformation.

- TMT improves strength and hardness to higher values compared to conventional aging.
- As the weight percentage of magnesium increases in the alloy, the hardness, strength, wear resistance increase with the decrease in ductility.
- With the same magnesium weight percentage in the alloy, an optimum weight percentage of Zinc (5%) is required to get better combination of properties.
- Al-5Zn-3Mg alloy shows the best combination of properties like strength, hardness, wear resistance and ductility.
- Thermomechanical treatment improves ductility with higher hardness and strength if it is properly designed.

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