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Development and Design of High Strength AA7xxx + 1% SC Aluminium Alloy by Precipitation Hardening Using AUTO LISP AND ANSYS: Study of Knuckle Joint by Replacing Cast Iron to AA7xxx +1%SC Alloy

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Abstract

In the present study, tensile and wear behaviour of AA 7xxx alloy and AA 7xxx + 1% Sc were studied. Casting process was used to produce AA 7xxx alloy. AA 7xxx + 1%Sc alloy reveals distribution of fine precipitates and intermetallic compounds in the α-aluminium matrix. In order to improve the mechanical properties and condition the microstructural features, precipitation hardening treatment was carried out by keeping temperature and time as variables. Ageing treatment was carried out at 120°C with varying time interval. Tensile and hardness studies were carried out on the aged alloys. There is a greater increment in strength and hardness at precipitation alloy. Wear behavior of the alloy was studied using the pin-on-disc technique with varying load and keeping sliding speed and time as constant. Precipitation hardened alloy shows better wear resistance than that of cast and solutionized alloy. Present heavy vehicles' using knuckle joint cast iron replaced in AA 7xxx + 1% Sc aluminum alloy. The objective of our project is to create all the entities of a Knuckle joint when it is given the deciding parameters like the diameter, d and length of joint e.t.c. To achieve this, complete design and drawing of different parts has been made and the whole procedure implemented with Auto Lisp the output satisfactorily. The drawing time and designing time of such processes thus reduced by different automobile industries. Our work development and design of high strength AA7xxx + 1% Sc aluminum alloy Tensile and wear behaviour of precipitation hardening by Automated graphical creation of Knuckle Joint when supplied with the defined parameters using Auto Lisp. Experimental works comparing ANSYS software and DOE (Design of Experiment)

Keywords: AA 7xxx, AA7xxx+1%Sc, Precipitation hardening, Wear behaviour, Auto Lisp, ANSYS.

1. Introduction

A material possessing desirable properties is the recent requirement in engineering applications. Light weight, formability and strength are the most important properties opted by the designer in the selection of a material for most of the advanced engineering applications. In specific, AA7xxx series alloys are widely used in aerospace applications due to their good specific strength, formability, resistance to various corrosive media, etc.

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Proper selection of alloying additions and thermo-mechanical processing are to be considered as a key strengthening factors which facilitates the formation of the required compounds and refining grain size. It was reported that increasing alloying additions resulted in forming complex intermetallic compounds [1-3], either soluble or insoluble in nature. Al-Sc alloys have excellent mechanical properties at ambient and elevated temperatures due to the presence of a high number density of elastically hard Al3Sc precipitates [4-5]. In addition of scandium, the high thermal stability of the Al3Sc precipitates will improve the strength of these alloys at high temperature [6]. The high response to precipitation hardening mechanisms is a homogeneous dispersion of Al3Sc particles, formed during solid solution strengthening and grain boundaries strengthening mechanisms [7]. It was proved that cryo rolling of aluminum alloys had resulted in ultrafine grains (UFG) with sufficient ductility. The cold rolling process cannot be used to produce UFG structure in AA7xxx alloys due to its high strength, poor ductility and high stacking fault energy. When the forming operation was carried out at room temperature, the quality of the surface of a final product was poor. It had been reported that the surface quality and improved ductility in high strength alloy could be obtained by conducting forming operation in the temperature range from 100 to 450˚C [8-9]. Wear and tear of engineering components is the big issue in industries such as automotive, etc. Wear studies of aluminum alloys and composites were widely studied many researchers [10-13]. We know that during working condition knuckle joint failure is subjected to high stress. As knuckle joint is flexible element which can be easily replaced [14]. So we can take for analyzing purpose. Then we are using experimental and ansys software for analyzing knuckle Joint replaced Cast iron to AA7xxx +1%Sc alloy.

2. Experimental Procedure

AA7xxx (Al-12Zn-3Mg-2.5Cu) aluminium alloy round billet was fabricated by casting method, chemical composition of AA 7xxx alloy with 1% Sc. The sizes of the die were 350mm x 50mm. In order to understand the hardening (T6) behaviour, the alloy was solutionized at 450°C for 2 hrs. Ageing treatment was done at 120°C with different time interval. Microstructural analysis was carried out on cast alloy and Aged alloy using optical microscopy and electron microscopy (SEM & TEM). Mechanical properties such as hardness and tensile studies were conducted on cast and precipitation hardened alloy. Tensile and hardness tests were conducted using Tinius Olsen, UK (Model: H50 KS) tensile machine and Wilson hardness, respectively. AA7xxx + 1%SC alloy were subjected to TEM samples were prepared to the size of 1cm x 1cm x 1mm. The alloy was further polished and manually thinned up to 100µm with the help of disc polishers using 80-1800 grade polishing papers. Polished alloy were further thinned by ion-milling. TEM investigation was carried out on rolled alloy by using JEOL TEM, working at 200 kV.

Dry sliding wear test was conducted using a conventional pin-on-disc testing machine to appraise room temperature wear behavior of the AA7xxx + 1%Sc aluminum alloy. Wear test samples were prepared as per ASTM G99 standards. The specimen (cylindrical pin) size was 6 mm diameter and 12 mm length. The rotating disc was made up of EN-32 steel with hardness of 65HRC. Weight loss was determined from the final and initial weight with the help of precision electronic balance accuracy of 0.001g. The tests were conducted with varying load (10N to 40N) at the constant speed of r.p.m for the distance of 2000m. The schematic diagram of pin on-disk and samples are shown in fig 1. Parameters taken constant

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during sliding wear test: Distance between centre of disc and centre of sample (r) as 21.8mm; Diameter (d) as 43.6mm; Velocity (V) as 1.2 m/s. From these parameters, rotational speed (N) was calculated based on the equation V = πdN/60 and time was calculated based on the equation Displacement / Velocity. Further, wear rate calculations are made based on Deepak Singla et al (2013) work.

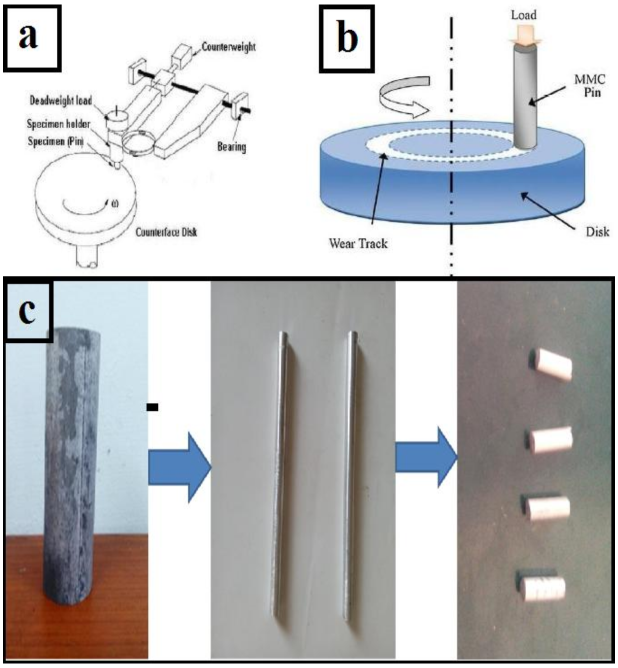

Fig1. a) Pin on disc set up b) Pin and disc contact c) Sample preparation from as cast.

3. Results and Discussion

3.1 Microstructural Characterization

Micrographs of AA7xxx alloy AA7xxx with 1%Sc aluminium alloy various conditions shown in fig. 2 (a & b). The microstructure of AA7xxx with Scandium shows α-Al matrix and complex intermetallic compounds. The grain size of cast alloy is the range of 20-30µm. After addition of the 1 wt (%) scandium grain size range of 5-10µm. Microstructures of solutionized and aged AA7xxx+ 1%SC alloy are shown in fig. 2 (c & d). The structure of aged alloy shows dispersoids and fine precipitates. During solutionizing treatment, the chemical composition of matrix grains is getting changed. The grains of solutionized alloy are rich with Cu and Zn than that of grains of cast alloy. The complex intermetallic compounds are predominantly Al_6CuMg_4, Al_2Cu and $MgZn_2$ and Al_2CuMg by non-equilibrium solidification addition of 1 wt (%), Scandium form dispersoids Al_3Sc shown in XRD pattern of Fig. 3.

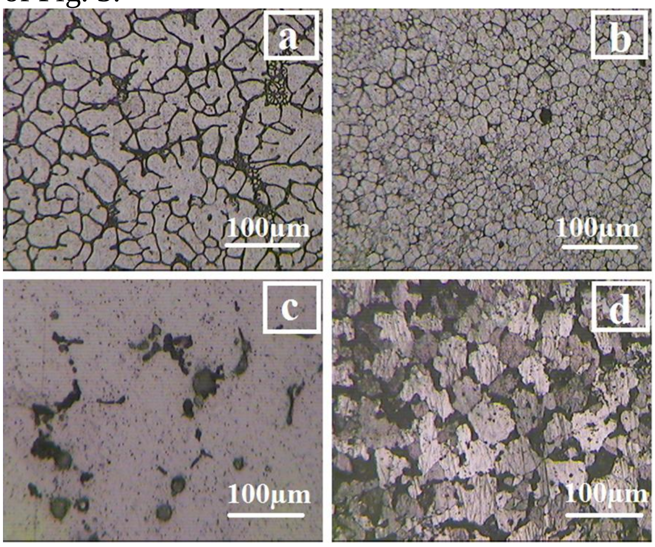

Fig. 2 Microstructure of AA7xxx alloy with different processing conditions (a) AA 7xxx Cast, (b) AA 7xxx + 1%Sc (b) AA 7xxx + 1%Sc Solutionized and (c) AA 7xxx + 1%Sc Aged.

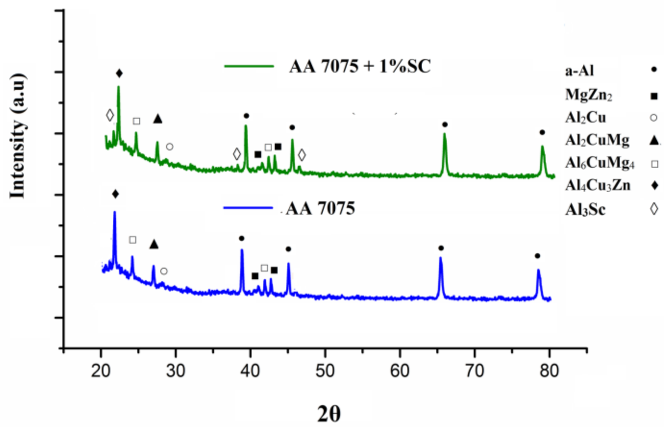

Fig. 3 X-ray diffraction patterns of AA 7xxx alloy and AA7xxx + 1%Sc

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3.2 Mechanical properties

Precipitation hardening behaviour of AA7xxx with 1%Sc alloy micro Vickers hardness values of the alloy with different processes are given in Table 1. The hardness values of cast and solutionized conditions are 171±5Hv$_{0.3}$, 188±5Hv$_{0.3}$, 114±3Hv$_{0.3}$ and 136±3Hv$_{0.3}$ respectively. Solutionized alloy results shows lower hardness than that of cast alloy, which is due to dissolution harder precipitates in the matrix. The undissolved precipitates such as Al_6CuMg_4 and Al_2CuMg are coarser in size and their contribution is minimal in enhancing hardness. The peak hardness is obtained at different ageing temperature, 198±4Hv$_{0.3}$ for 20hrs and 212±5Hv$_{0.3}$ for 16hrs at 120°C and 160°C, respectively. After attaining peak hardness, the hardness is getting reduced by over-ageing. The peak hardness values of aged alloy are much higher than conventional AA7xxx and AA7xxx with 1%Sc alloy.

Table 1. Hardness values of AA7xxx with 1%Sc alloy with different conditions

Conditions	Hardness Values (Hv)			
As Cast	171 ± 5			
As Cast + 1%SC	188 ± 5			
Solutionized(Ascast) (450°C +2hrs)	114 ± 3			
Solutionized(1%SC) (450°C +2hrs)	136 ± 3			
Ageing Time (hrs)	Hardness Values (Hv)			
	As Cast		As Cast + 1% SC	
	120°C	160°C	120°C	160°C
4	118 ±5	121±5	126±5	145±5
8	132±5	154±5	140±5	173±5
12	150±5	183±5	165±5	186±5
16	168±5	191±5	189±5	198±5
20	176±5	193±5	198±5	212±5
24	185±5	199±5	210±5	221±5
28	172±5	176±5	207±5	215±5

Mechanical properties of AA7xxx and AA7xxx with 1% Sc alloy with different conditions are shown in Table 2. The tensile strength of AA7xxx and AA7xxx with 0.5% Sc cast, solutionized and aged alloy is 424MPa, 480MPa, 359MPa and 642MPa and the elongation is 3%, 2%, 7% and 6.5%, respectively. AA7xxx and AA7xxx with 1% Sc alloys has resulted good strength by non-homogenous nature and poor ductility of cast alloys. Age hardened aluminium alloy exhibits enhanced mechanical properties than that of cast alloy and solutionized alloy with 6.4% ductility. A good combination strength and ductility in bulk nano-structured AA7xxx with 1% Sc alloy had been developed by introducing very fine secondary phase particles in the matrix. Enhancement of strength and ductility in alloy was attributed to an accumulation of dislocations, resistance to dislocation-slip by compounds, solid solution, precipitation hardening and dispersion hardening. Precipitation hardening has resulted increment in UTS than that of cast alloy with good incremental ductility. This is attributed by nano-scale size of precipitates distributed homogeneously throughout the matrix addition of AA7xxx + 1%Sc alloy.

Table 2.Mechanical properties of AA7xxx alloy with different conditions

S.No	Conditions	($Hv_{0.3}$)	Yield strength (MPa)	UTS (MPa)	% Elongation
1	Cast	171±5	358±10	424±10	3.0±1
8	Cast + Sc (1%)	188±5	432±10	480±10	2.0±1
9	Solutionized + Sc (1%)	150±5	272±10	359±10	7.0±2
10	Aged + Sc (1%)	205±5	525±10	642±10	6.4±2

3.3 Wear behavior of precipitation hardened (T6) AA7xxx+1%Sc alloy

Wear data obtained for AA7xxx + 1% Sc aluminum alloy at different conditions are tabulated (Table-3). Fig. 4 relates the wear rate with increasing load. Wear rate of cast ($4.11x10^{-5} mm^3/m$) condition is more than aged ($3.21x10^{-5} mm^3/m$). Wear rate of cast is 20% more than that of aged conditions. Wear rate increases with increase in applied load from $1.8x10^{-5} mm^3/m$ for 10N to $4.11x10^{-5} mm^3/m$ for 40N load with an increase of 55%. Coefficient of friction almost remains constant for all the time of wear. Coefficient of friction increases from 0.43 for 10N load to 0.54 for 40N load causing overall increase of 55%.

Table 3. Wear data obtained for AA 7xxx + 1%Sc alloy at different conditions

Conditions	Mass loss (g)	Volume (mm^3)	Wear rate (mm/m^3)	COF
Cast				
10N	0.100	35.71	1.78×10^{-5}	0.43
20N	0.145	51.78	2.60×10^{-5}	0.48
30N	0.190	67.85	3.40×10^{-5}	0.52
40N	0.230	82.14	4.11×10^{-5}	0.54
Solutionized (450°C-24hrs)				
10N	0.135	48.21	2.41×10^{-5}	0.32
20N	0.180	64.28	3.21×10^{-5}	0.36
30N	0.230	82.14	4.10×10^{-5}	0.39
40N	0.280	100	5.00×10^{-5}	0.41
Aged (120°C-20hrs)				
10N	0.080	28.57	1.428×10^{-5}	0.52
20N	0.120	42.85	2.142×10^{-5}	0.54
30N	0.160	57.14	2.857×10^{-5}	0.59
40N	0.200	71.42	3.214×10^{-5}	0.68

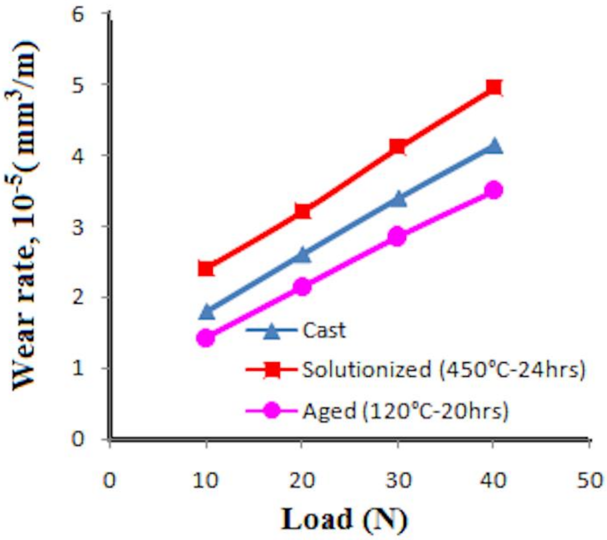
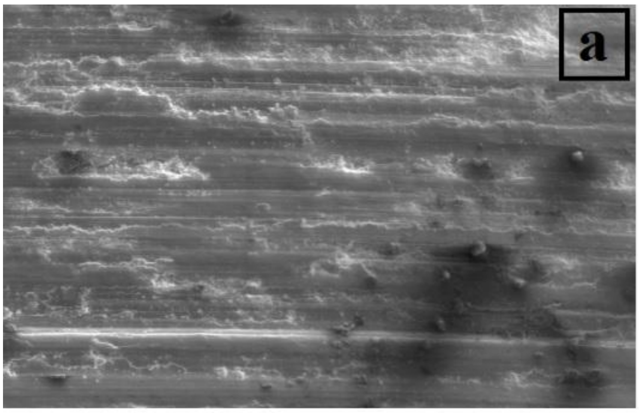


Fig 4 Wear rate of different loads on AA 7xxx + 1%Sc alloy a) Cast b) Solutionized and c) Aged (120˚C-20hrs) conditions

Figure 5 shows the worn surface of AA 7xxx + 1%Sc alloy at different conditions cast, solutionized and aged. Figure 5a shows the worn surfaces of the cast alloy and it can be observed that the alloys at low velocity mild oxidation wear marks are visible. Figure 5b and 5c show the worn surface of solutionized alloy and Aged (120˚C-20hrs). The worn surface has mainly oxidation marks and debris particle due to delamination.



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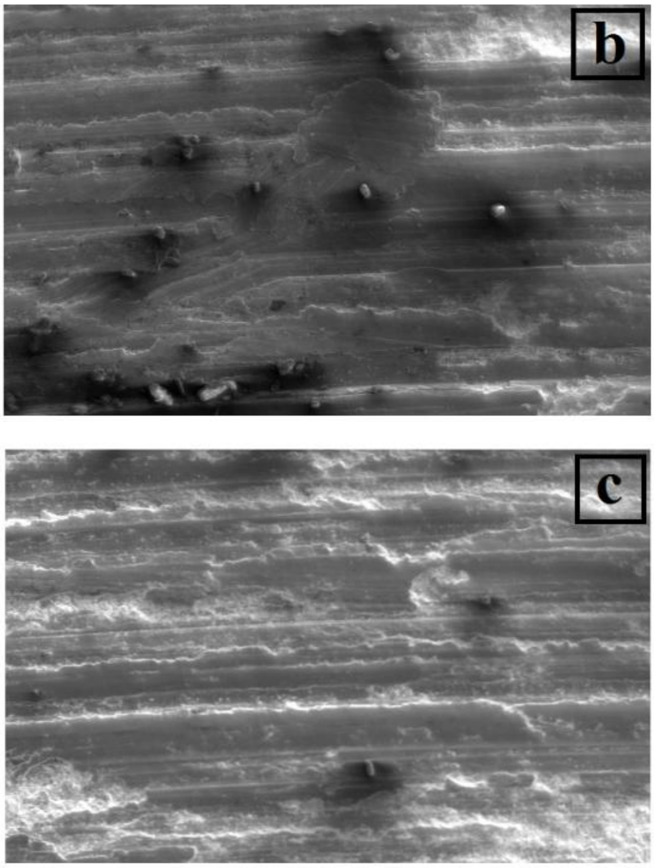
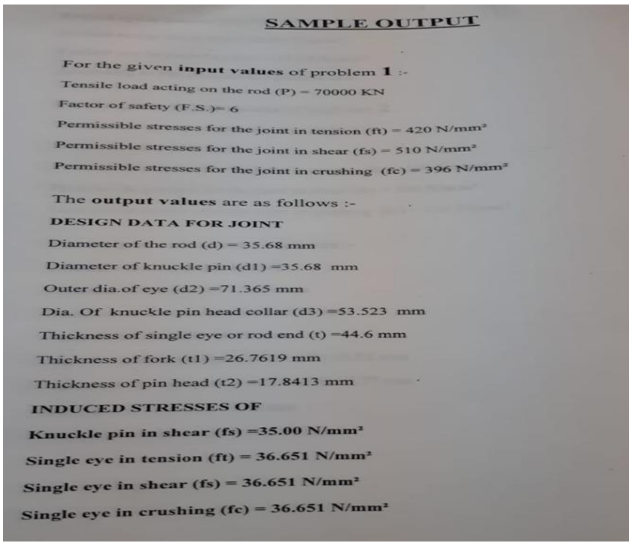


Fig 5 SEM micrograph wear track surface of AA 7xxx + 1%Sc alloy after T6 treated at 120˚C for 20hrs in different conditions a) Cast b) Solutionized and c) Aged (120˚C-20hrs) conditions

3.4 AUTOLISP PROGRAM FOR KNUCKLE JOINT

```
(DEFUN C:kjoint       ()
  (COMMAND "cmdecho"
            0
            "plan"
            ""
  )
  (SETQ         text1 "WELCOME TO THE
PROJECT ON"
         text2 "KNUCKLE JOINT DESIGN"
         text3 "PLEASE ENTER THE
REQUIRED DATA IN THE DIALOUGE
BOX"
         text4 "WHICH WILL BE
DISPLAYED AND PRESS [OK] TO
GENERATE THE JOINT"
 (defun c:elpo ()
  (alert
   "The Knuckle Joint may be readily
disconnected for adjustments or\n
  repairs. The joint use may be found in the
link of a cycle chain,\n
  tie rod joint for roof truss, valve rod joint
with eccentric rod,\n
  pump rod joint, tension link in bridge
structures and lever.\n
  The materials used for the joint may be steel
or wrought iron."
  )
)
```

Out Put



SAMPLE OUTPUT

For the given **input values** of problem **1** :-
Tensile load acting on the rod (P) = 70000 KN
Factor of safety (F.S.)= 6
Permissible stresses for the joint in tension (ft) = 420 N/mm²
Permissible stresses for the joint in shear (fs) = 510 N/mm²
Permissible stresses for the joint in crushing (fc) = 396 N/mm²

The **output values** are as follows :-
DESIGN DATA FOR JOINT
Diameter of the rod (d) = 35.68 mm
Diameter of knuckle pin (d1) =35.68 mm
Outer dia.of eye (d2) =71.365 mm
Dia. Of knuckle pin head collar (d3) =53.523 mm
Thickness of single eye or rod end (t) =44.6 mm
Thickness of fork (t1) =26.7619 mm
Thickness of pin head (t2) =17.8413 mm
INDUCED STRESSES OF
Knuckle pin in shear (fs) =35.00 N/mm²
Single eye in tension (ft) = 36.651 N/mm²
Single eye in shear (fs) = 36.651 N/mm²
Single eye in crushing (fc) = 36.651 N/mm²

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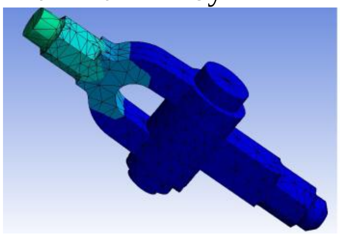
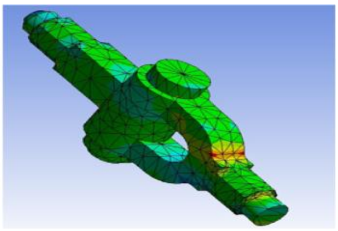
ANSYS

Contents
Units
Knuckle Joint (A4)
Geometry n Parts, Materials, Coordinate Systems, Connections, Contacts, Contact Regions and Mesh
Static Structural (A5)
Analysis Settings, Loads, Solution (A6), Solution Information, Results, Stress Tool and Safety Factor
Material Data
Aluminum Alloy





4. Conclusions

1. Cast AA 7xxx, AA7xxx + 1%Sc wt. (%) alloy shows coarse intermetallic compound, both soluble and insoluble, homogeneously distributed throughout the matrix and grain boundaries.
2. Precipitation behaviour of AA 7xxx and AA7xxx + 1%Sc wt. (%) alloy is a bit sluggish due to the presence of insoluble intermetallic compounds which delay the solutionizing of soluble compounds and evolution of fine precipitates during ageing. It is interesting to note that there is a precipitate free zone around the insoluble coarse intermetallic compounds, attributed by restricted atom diffusion around insoluble compound
3. Precipitation hardening has resulted increment in UTS than that of cast alloy with good incremental ductility. This is attributed by nano-scale size of precipitates distributed homogeneously throughout the matrix addition of AA7xxx + 1%Sc
4. Precipitation hardening has resulted 40% increment in UTS than that of cast alloy with 6% ductility. This is attributed by nano-scale size of precipitates distributed homogeneously throughout the matrix
5. Precipitation hardened alloy shows increased wear resistance than that of cast and solutionized alloy. However, the co-efficient of friction is low.

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