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RESEARCH ARTICLE

MATERIAL CHARACTERIZATION OF ADVANCED ALUMINIUM ALLOYS

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ABSTRACT

This project deals with the material characterization of Al-Mg alloys namely AC300 and 7021 undergoing Shock Heat Treatment where the specimen is heated for 5 seconds to a temperature of 350°C. AC300 undergoes single stage shock heat treatment and the various material properties are considered like yield stress and temperature and elongation and temperature curves are plotted and that showed a different trend unlike the usual trend of decreasing yield stress with increasing temperature. Hence there was a need for modeling the material for optimization and improvement in the material properties. 7021 was also tested under single stage shock heat treatment and the two-stage heat treatment was also applied to it where there was certain amount of pre-strain given to the specimen before heat treating it. But it was seen that there was no effect of pre-strain on the specimen as the yield stress remains the same even for different values of pre-strains. Hence it was concluded that only the change in the properties of the materials is because of the heat treatment, Therefore, a mathematical model was devised for material characterization of the alloys. Thus curve fitting was done to determine the equation for modeling the alloys considering only single stage shock heat treatment. The characteristics curve equations could be varied by changing the values of the constants for further detailed experiment and study on various properties of AC300 and 7021.

INTRODUCTION

Background and Purpose

In the field of manufacturing engineering, the basic building block of any part/series to be manufactured is the material used. Hence for that purpose having the perfect material with the appropriate properties is very much essential to set the foundation straight and to perfection. The knowledge of material science comes in handy to design and analyse the properties of the material to be used for manufacturing. Hence, it is instrumental to identify the correct blend of materials for the alloys, which are the structural and functional component of manufacturing. This alteration in the material for optimum results and outputs can be done material characterization which is done my constitutive modelling the material for efficient properties.

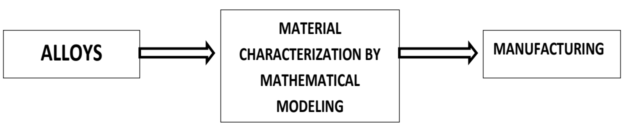

Fig 1 Basic process flow for manufacturing

There's a necessity to modify the properties of the material used for developing the alloy for manufacturing for better usability, reliability so as to yield better results for the finished products. Without modifying the properties the materials can be used to manufacture parts of an automobile no doubt, but then that would create certain problems in the long run when we go for designing and simulations in the long run, result si loss of time, energy and money. So in order to avoid these losses we need to characterize the material according to various testing conditions and behaviour of the material. Therefore, this generates a need for a mathematical model to overcome the randomness and uneven nature of the curves and to generate more accurate and smooth flow curves for studying the yield properties of the material before approving it for series use.

Objective of the Project

This project focuses on the study and analysis of the behaviour of the alloys 7021 and AC300 by studying the variation of yield stress and elongation against various temperatures of Shock Heat Treatment process and hence developing a mathematical model by fitting of curves using MS-Excel so as to develop better material characteristics. The aluminium alloys used here are AC300 and 7021. These alloys are subjected to Shock Heat Treatment after which the respective curves are plotted and we compare the behaviour of these materials with the standard behaviour of a material undergoing heat treatment and find the true stress and strain curves. These curves are used for determining the material characterization, hence a mathematical model is finally developed so as to fit these curves and to obtain an equation with X and Y. This equation gives the model of variation of yield stress and elongation of the material with various temperatures. The values of the coefficients of x in the model equation determine the material behaviour. Thus by changing the values of these coefficients

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we can find out the changes in the material behaviour and hence find the suitable model depending upon the conditions and requirements.

This project was aimed at developing a mathematical model for the given alloys to study the behaviour and properties of 6-series and 7-series aluminium after using a latest heat treatment method named Shock Heat Treatment.

Heat Treatment Processes

Shock Heat Treatment (SHT)

Daimler AG has developed using a latest heat treatment technology named Shock Heat Treatment. In this process the sheet metal is heated to a temperature of 350°C within a time frame of 5 seconds. This fast process of heating the sheet to a temperature as high as 350°C in a very small time window of 5 seconds makes it heating like a shock, hence the name Shock Heat Treatment.

Single Stage SHT

In this process of SHT, the sheet initially undergoes tempering process in which the material is brought to T6 temper condition so as to be conducive for Shock Heat Treatment. Then, after a waiting period of three weeks the sheet is heated to 350°C within 5 seconds and hence it is followed by the tensile test.

Two Stage SHT

In a similar way as that of single stage SHT here also the sheet undergoes tempering initially to make it T6 temper conditions. Then after holding the sheet for three weeks the sheet material undergoes pre-forming by giving certain percentages of pre-strains to the sheet metal and finally it undergoes shock heat treatment where it heated up to 350°C followed by tensile test.

W-Temper

In this process of heat treatment the specimen undergoes tempering process at first and then without any waiting period it is heated right after tempering in the room temperature only, followed by tensile test.

METHODOLOGY

AC300

Single Stage SHT

The sample specimen was heated to 580°C for 20 minutes and quenched in water (Tempering). This is done to bring the specimen to T6 form before performing shock heat treatment. Then after a holding period of three weeks the specimen undergoes SHT where it's heated rapidly to 350°C in 5 seconds and the temperatures are recorded starting from room temperature till 350°C. For rolling angle 0° three specimens were considered to get better accuracy in results. But for rolling angles 45° and 90° three specimens were considered each from temperatures 80°, 225° and 350° only. Then the curves between yield stress and temperature and also elongation and temperature were plotted.

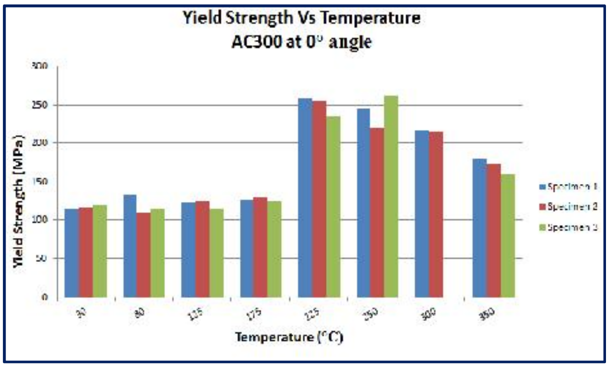

Fig. 2 Temperature vs Yield Stress (AC300)

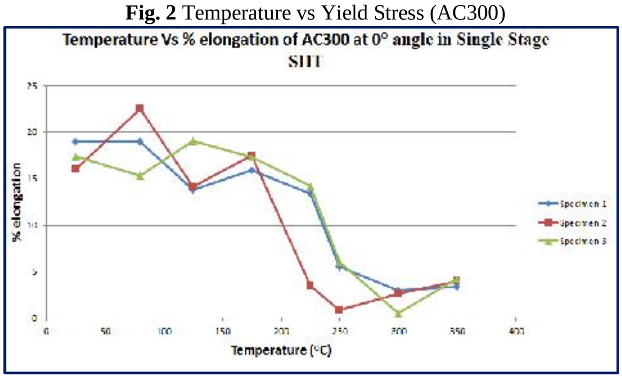

Fig. 3 Temperature vs Elongation (AC300)

From yield stress vs temperature curve we see that there's a deviation in the general pattern of the curves i.e instead of decreasing with the increasing temperature the yield stress remains almost constant. This occurs because of the material behaviour of AC300. AC300 has its yield stress properties almost unchanged with increase in temperature till 205°C. After that it increases rapidly and then gradually decreases like the normal trend. That's a unique property as far as metals and its alloys are concerned.

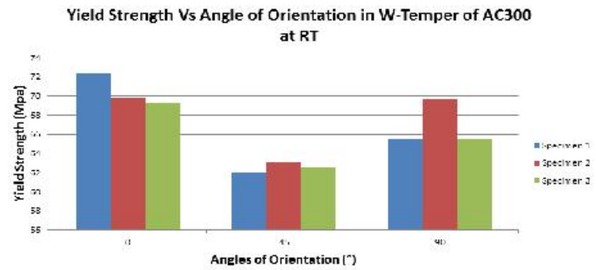

Fig. 4 Yield Strength vs Orientation Angle in W-Temper

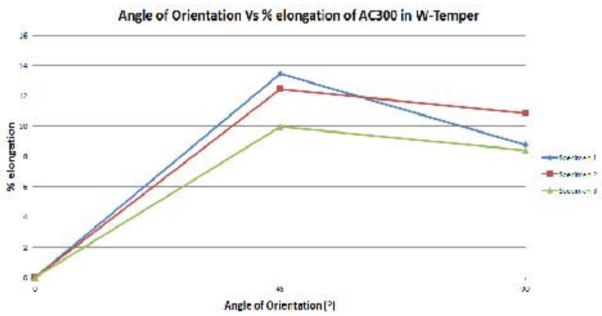

Fig. 5 Elongation vs Angle of Orientation in W-Temper

W-Temper

In case of W-Temper condition the specimen undergoes tempering process and then is immediately heated at room temperature without any waiting period. Hence in this case we consider three specimens each from different rolling angles i.e. 0°, 45° and 90° respectively.

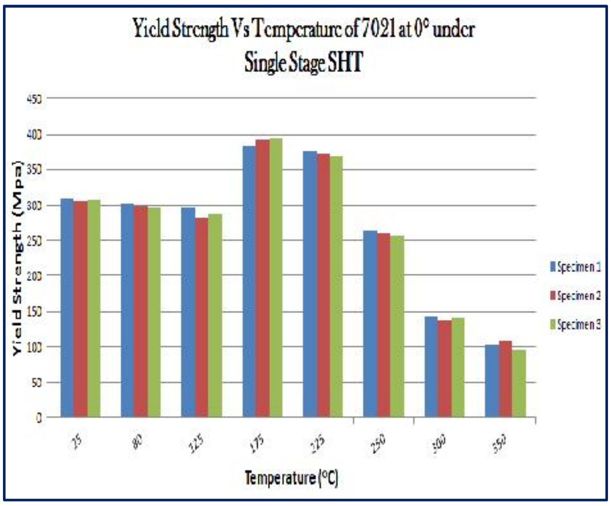

Fig. 6 Yield Stress vs Temperature in Single Stage SHT for 7021

Al 7021

Single Stage SHT and W-Temper

In case of 7021 the single stage shock heat treatment and W-Temper follow the same process steps as that in case of AC300. The process is the same. Given below are the results of the study and tests undertaken with 7021 in single stage SHT and W-Temper.

Two-Stage Shock Heat Treatment

In case of two-stage shock heat treatment, first the specimen undergoes tempering by heating it up to 465°C and then quenching it in water and then there is a waiting period of three weeks. After this age hardening process the specimen pre-formed by rendering different percentages of pre-strains like 3%, 6% and 9%.

After giving the necessary pre-strains the specimen os subjected to shock heat treatment with temperature ranging from room temperature till 350°C and for three different rolling angles like 0°, 45°, 90°. And finally the tensile test is done and the necessary curves were plotted.

As mentioned before, IIHT is a short-term, localized heat treatment embedded between two conventional cold forming steps (Fig. 1). In the first step the component is deep drawn up to a specified draw depth well before the onset of necking.

In the next step, the pre-formed parts are locally induction heat treated, predominantly adjacent to forming critical areas, for up to 350°C and for about 5 seconds. Then, the pre-forms are cooled down to room temperature before performing the next forming operation to obtain the final product.

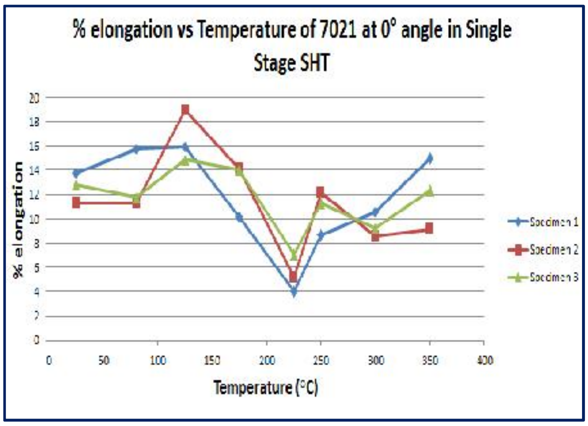

Fig. 7 Elongation vs Temperature in Single Stage SHT for 7021

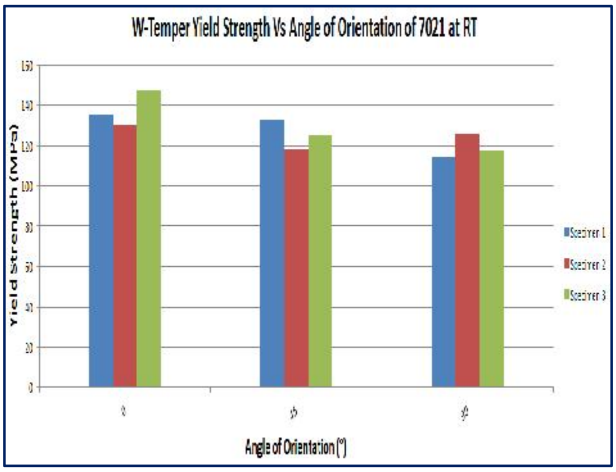

Fig. 8 Yield Stress vs Rolling Angle for 7021

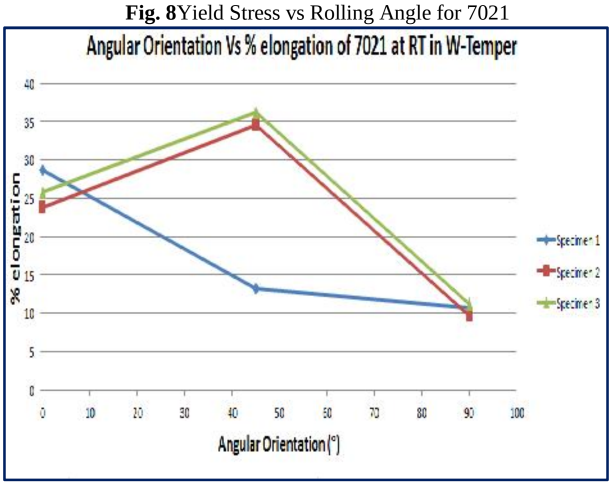

Fig.9 Elongation vs Rolling angle for 7021

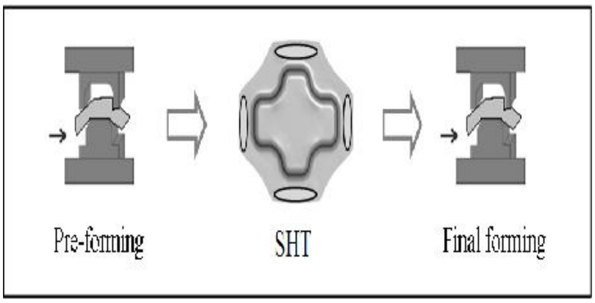

Fig.10 Two-Stage Shock Heat Treatment

For 3% pre-strain and post-strain curves

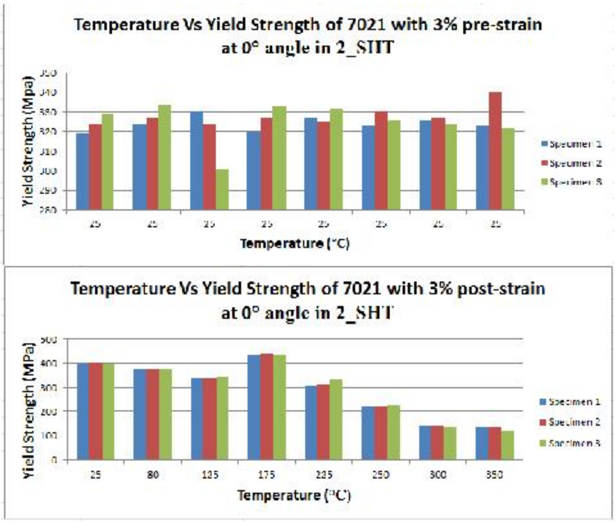

Fig.11 Yield Stress vs Temperature with 3% pre-strain

For 6% pre-strain and post-strain curves

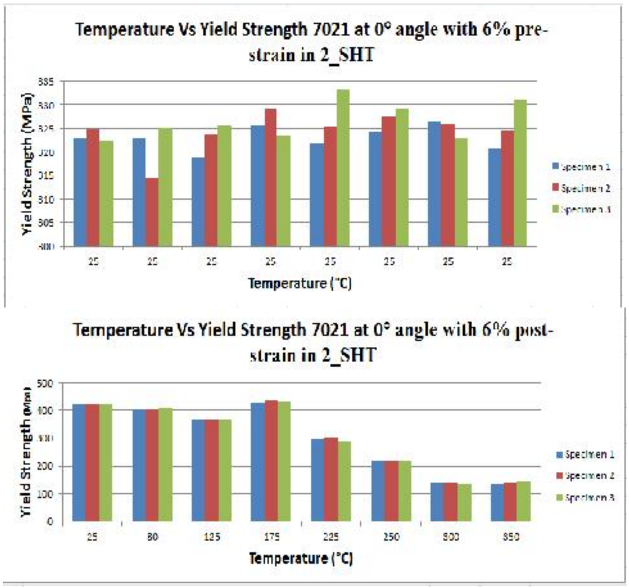

Fig.12 Yield Stress vs Temperature with 6% pre-strain

For 9% pre-strain and post-strain curves

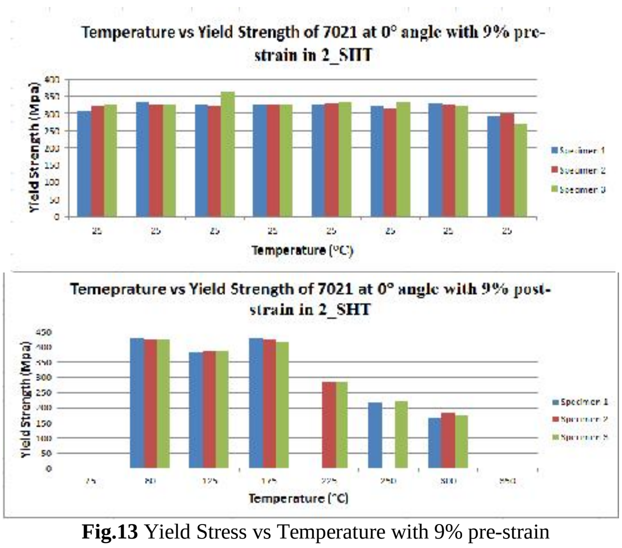

Fig.13 Yield Stress vs Temperature with 9% pre-strain

The Elongation Vs Temperature for different pre-strain is plotted below

For 3% pre-strain

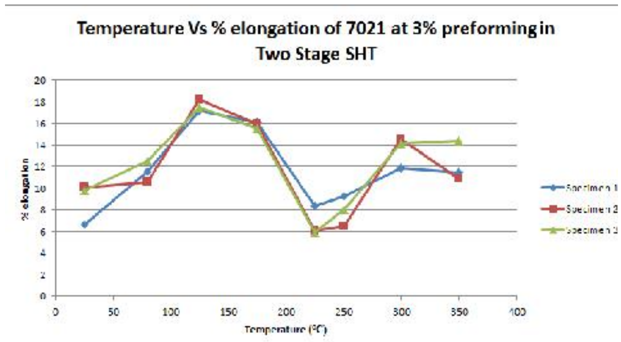

Fig.14 Elongation vs Temperature with 3% pre-strain

For 6% pre-strain

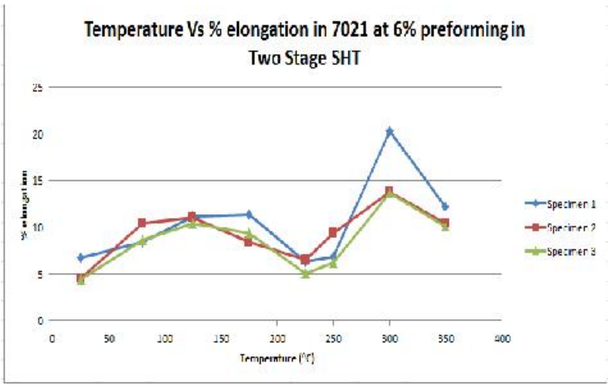

Fig.15 Elongation vs Temperature with 6% pre-strain

For 9% pre-strain

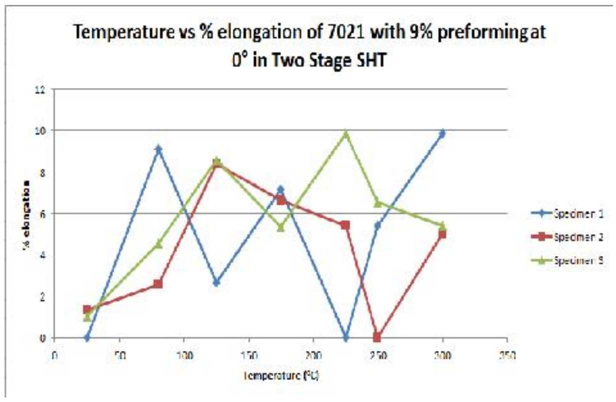

Fig.16 Elongation vs Temperature with 9% pre-strain

The Idea of Pre-Forming: It's Implication

The objective of pre-forming operation is to induce work hardening, which increases the dislocation density in the crystal lattice. This is associated with an increase in the yield strength accompanied by a simultaneous reduction in fracture elongation. The defined partial induction heat treatment of the pre-deformed component in the second subsequent process step reduces the work hardening introduced earlier. As a result the yield strength of the material is reduced, which leads to a partial reduction of dislocations. This leads to increase in material elongation and can therefore be used for a further cold forming step. In this case, the temperature of the SHT process is below the recrystallization temperature of the material. The objective here is merely to allow the alloy to recover by various means including the reduction of dislocation density. In the final cold forming step, the component is drawn up to its final geometry. The SHT process thus makes it possible to produce complex shapes, which is otherwise not possible by a conventional cold forming process.

Material Characterization

The tensile tests were carried out in three steps. In the first step, the samples were pre-strained up to approximately 3%, 6%, and 9%. The pre-strained samples were then shock heat treated for about 5 seconds at different target temperatures to allow deformed grains to recover plastically at elevated temperature. Then the samples were clamped again in the tensile test equipment and drawn up to fracture at room temperature.

The figure below clearly shows the significant influence of temperature on the reduction of the work hardening and the increasing uniform elongation. A specimen pre-strained up to 3% with yield strength of 398 MPa, falls almost to 140 MPa at 350˚C.

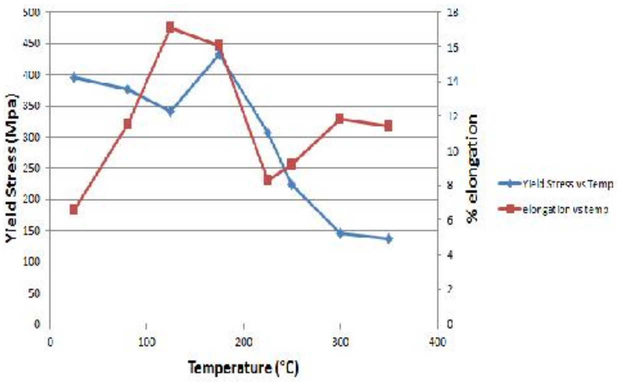

Fig.17 Mechanical properties of 7021 for 3% pre-straining and at different temperatures

The process window for the heat treatment is limited to a maximum object temperature of 350 °C. This is due to the formation of undesired coarse grains that are generally visible on the surface. At this temperature, the brief process time is not sufficient to cause recrystallization and a coarse grain formation. However, the brief induction heat treatment is sufficient to ensure the desired reduction in the introduced work hardening.

Modeling the Effect of Induction Heat Treatment

As mentioned before, the application of an SHT always leads to a lowered hardening response of the material, for pre-strained as well as for unstrained initial condition. In case of pre-strained material the lowering of the yield stress is depending on both, heat treatment temperature and amount of initial pre-strain. Thus a more general approach is necessary. A simple method to quantify the effect of heat treatment on the material hardening behavior is to calculate the difference of the yield stress ($\Delta\sigma$) between the base material at room temperature and the pre-strained heat treated material.

Given below are the True Stress-True Strain curves for 7021, Two-Stage SHT for 250°C, 300°C and 350°C respectively of Specimen 1.

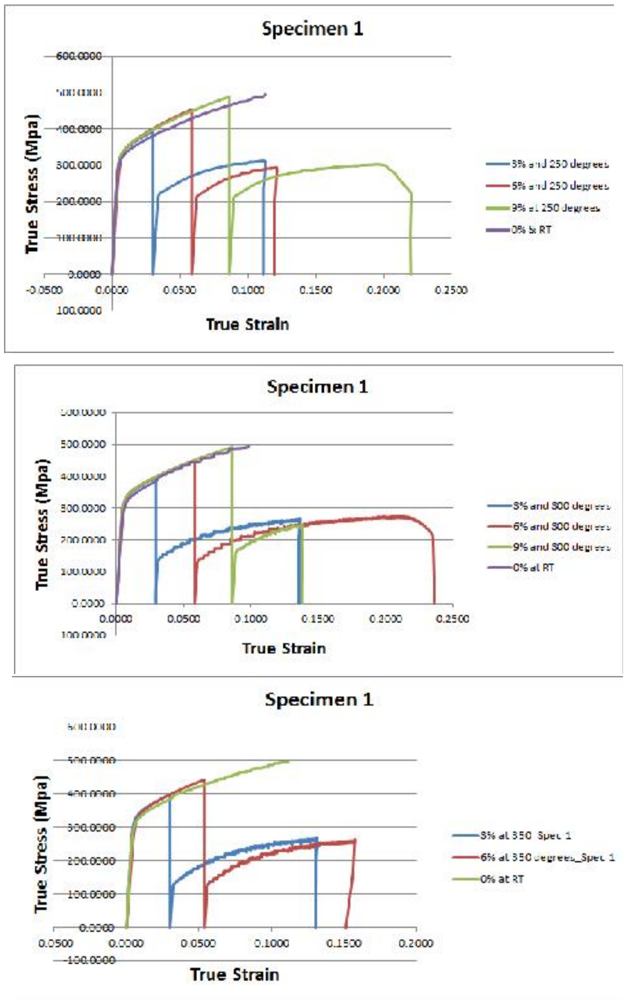

Fig. 18 True Stress and True Strain curves for 7021 with pre-strains 3%, 6%, 9%

Mathematical Model for Shock Heat Treatment

For 7021

The above curves show the before and after effects on the variation of true stress vs true strain of 7021 in two-stage SHT when its pre-formed with certain percentages of pre-strains. Hence by studying the curves we can conclude that the different percentage of pre-strains does not have any effect on the yield behavior of the material. We can pretty clearly observe that the yield stress of the pre-strained material after heat treatment remains same even for different values of the pre-strains. Thus in a nut shell, we can say that the properties of the material vary or changes on because of the heat treatment irrespective of the amount of pre-strains given. So, we can say that 7021 need not undergo two-stage SHT as the implication of pre-strains does not make any significant impact at all on the yield stress values of the material. Therefore, it was decided to consider only the single stage SHT and hence the modeling was done for single-stage only. So if we plot the curves for single stage SHT for 7021 we get the curves as shown below.

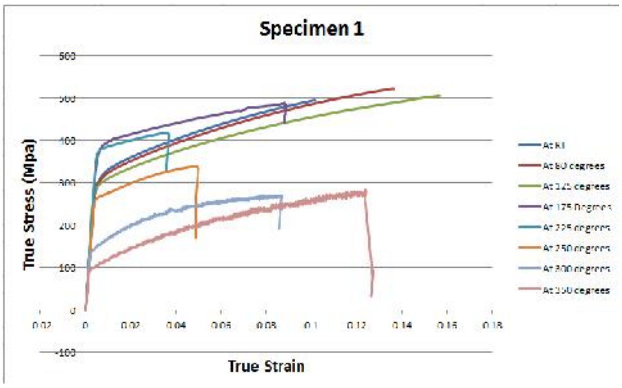

Fig. 19 True Stress and True Strain curves for 7021 under single stage SHT

The above figure shows the variation of true stress with true strain in a single stage SHT for 7021 without any pre-strains. This shows the normal trend of the stress strain curves under loading and resulting in fracture elongation. Thus, there was the need for developing a mathematical model so as to obtain the equation for the curve. This was done by curve fitting method using MS-Excel.

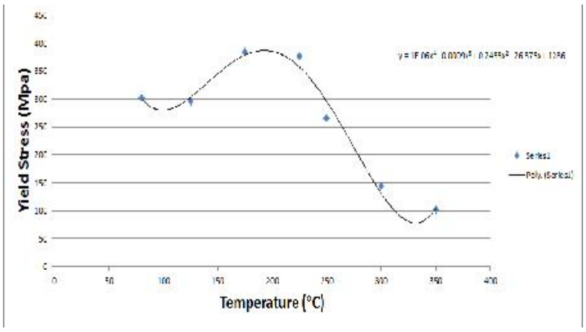

Fig.20 Material Model for 7021 yield stress vs temperature

Hence the equation for the model for ***Yield stress Vs Temperature*** is,

$$y = 1E\text{-}06x^4 - 0.0009x^3 + 0.2455x^2 - 26.875x + 1286$$

Where the constants are,

A= 1E-06
B= 0.0009
C= 0.2455
D= -26.875
E= 1286

The model for ***Elongation Vs Temperature*** is,

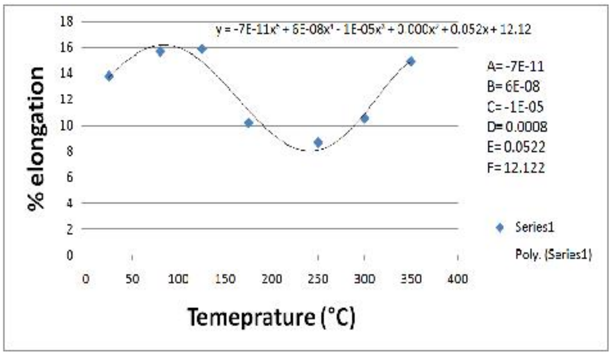

Fig.21 Material Model for 7021 elongation vs temperature

Equation for the mathematical model,

$$y = -7E\text{-}11x^5 + 6E\text{-}08x^4 - 1E\text{-}05x^3 + 0.0008x^2 + 0.0522x + 12.122$$

Where the constants are,

A= -7E-11
B= 6E-08
C= -1E-05
D= 0.0008
E= 0.0522
F= 12.122

For AC300

The parametric polynomial equation obtained from the curve fitting method for AC300 gives the following results and equations,

Model for ***Temperature Vs Yield Stress***

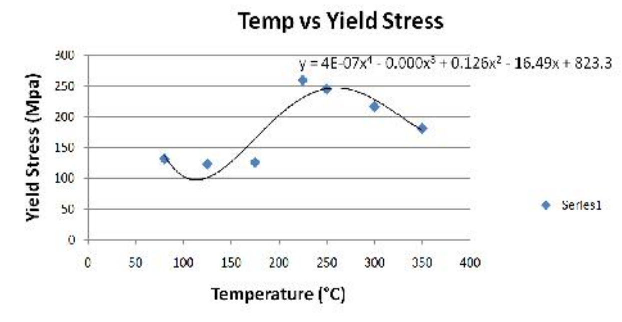

Fig.22 Material Model for AC300 yield stress vs temperature

Equation for the mathematical model,

$$y = 4E\text{-}07x^4 - 0.0004x^3 + 0.1263x^2 - 16.495x + 823.31$$

Where the constants are,

A= 4E-07
B= 0.0004
C= 0.1263
D= -16.495
E= 823.31

Model for *Temperature Vs Elongation*

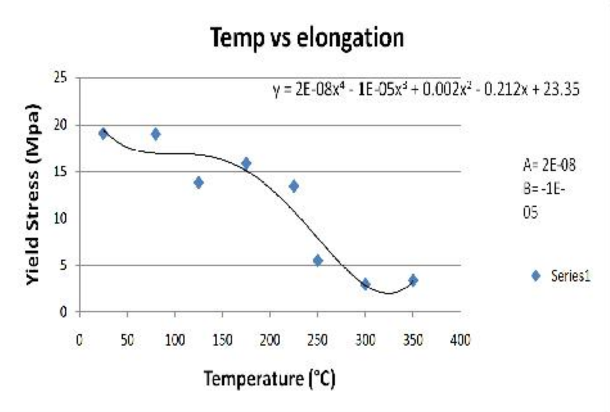

Fig.23 Material Model for AC300 elongation vs temperature

Equation for the mathematical model,

$$y = 2E\text{-}08x^4 - 1E\text{-}05x^3 + 0.0025x^2 - 0.2125x + 23.358$$

Where the constants are,

A= 2E-08
B= -1E-05
C= 0.0025
D= -0.2125
E= 23.358

CONCLUSION AND RECOMMENDATIONS

This report throws light on the study, analysis and development of various properties of Al-Mg alloys namely AC300 and 7021. In the first stage the results obtained from the tensile test done by BISS was thoroughly studied and analysed and the necessary graph were plotted. This project dealt with a latest technology developed for heat treatment of metals and alloys known as Shock Heat Treatment. Both of these alloys under study were treated with single stage and two stage shock heat treatments as well as W-temper situations. Then the required yield stress and temperature variations were studied and also the variation of elongation with temperature was plotted and considered. Then the two-stage shock heat treatment was not considered for heat treatment as there was no effect of the pre-strains on the yield behaviour of the material. Only the single stage method of SHT was taken into account. Moreover, this project revealed certain new facts like the strange behaviour of AC300, in which the yield stress remains unchanged with increase in temperature till 205°C and after that it increase and gradually decrease as the normal trend. Then after finalizing the method of heat treatment as single stage SHT, came the task of modelling the material according to the requirements so as to obtain a smooth flow curve to determine the characteristic equation, which has been described as material characterization. The material was modelled using MS-Excel by the method of curve fitting. Hence for both the alloys AC300 and 7021 the characteristic model curves were obtained for the variations of both yield strength an elongation w.r.t. temperature.

Thus the next step in this project shall be to simulate the meshed geometry of the cross die using LS-DYNA. The geometry is set up in Hyper Mesh and then it is simulated using LS-DYNA considering various parameters and conditions. By doing so, the effect of the various parameters can be changed and the respective plots and FLDs can be obtained. Basing on the results of the simulation we can conclude whether AC300 and 7021 are suitable and conducive to be used for manufacturing of Daimler cars or not. As of now basing the material model the material can be simulated for better picture and idea about the change in its properties and behaviour based on conditions and usability.

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