EFFECT OF Sb-Si ADDITION ON NECKING BEHAVIOUR OF Mg ALLOYS

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Abstract

The present study aims to investigate the necking behaviour of Mg-Sb-Si ternary alloy. Addition of Sb and Si to Mg introduces Mg_3Sb_2 and Mg_2Si intermetallic phases respectively which alters the morphology as well as the mechanical properties of the alloy. Ternary Mg-Sb-Si alloy with varying Si composition were developed by melting pure Mg with required amount of Sb and Si. Optical results of the alloy indicates the presence of rod shaped Mg_3Sb_2 phase which effectively refines the grain. Mg_2Si phase in form of a Chinese Script shape developed as a result of Si addition improves the tensile strength of the alloy. Analysis of necking behaviour using Comsol Multiphysics software is performed incorporating the data obtained from the tensile tests. Large plastic strain approach is selected since there is a multiplicative decomposition between the elastic and plastic deformation. Double dogleg Solver is employed to solve the problem considering the nonlinearity of the problem. It is inferred from the analysis that Mg_3Sb_2 enhances plasticity whereas Mg_2Si induces brittle fracture.

Keywords: *Ternary alloy, Si addition, Sb addition, Intermetallics, Necking behaviour and Comsol etc…*

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1. INTRODUCTION

Magnesium alloys are prevailing over Aluminum alloys for the very reason that they are having a higher strength to weight ratio. Various alloying elements are added to magnesium for improving its morphology as well as mechanical properties. It has been reported that[1,2,3] the high temperature properties and morphology can be improved by Si and Sb addition. The addition of Silicon leads to development of an intermetallic phase Mg_2Si having high melting point, high hardness, low density and low coefficient of thermal expansion [2].A rod shaped Mg_3Sb_2 intermetallics developed by Sb addition acts as a barrier for dislocation motion and grain boundary sliding[4]
Analysis of necking behaviour is important since it is related to the morphology of the alloy and is directly linked with the contribution of intermetallic phases. In the present work Mg-Sb-Si alloy with varying Si addition is developed, a uniaxial tensile test is performed to find out mechanical properties which is utilized for developing a nonlinear Isotropic hardening model for analyzing the necking behaviour using Comsol Multiphysics Software. Comsol Multiphysics is a finite element software for solving physics and engineering applications. The nonlinear analysis module is employed here to interpret the problem and subsequently solving it by large plastic strain assumption.

2. EXPERIMENT

Ternary Mg-Sb-Si alloy with varying Si composition were developed by melting pure Mg with required amount of Sb and Si. Steel cruicible under proper flux cover were employed for melting. Four sets of casting with required compositions were developed. The composition were analysed using Inductively Coupled Plasma Atomic Emission Spectrometer and the results are shown in table 1.

Table-1: Chemical composition of developed alloy

Alloy	Elements in weight percentage		
	Mg	Sb	Si
Mg+2%Sb	97.9	2.1	0
Mg+2%Sb+.5%Si	97.51	2.0	.49
Mg+2%Sb+1%Si	96.87	2.15	.98
Mg+2%Si+2%Si	95.92	2.1	1.98

2.1 Microstructure Results

For microstructure analysis samples of size 15mm dia and 10mm height was machined. After polishing and etching the specimens were studied on a Leitz–Metalloplan optical microscope. Microscopic results are shown below.

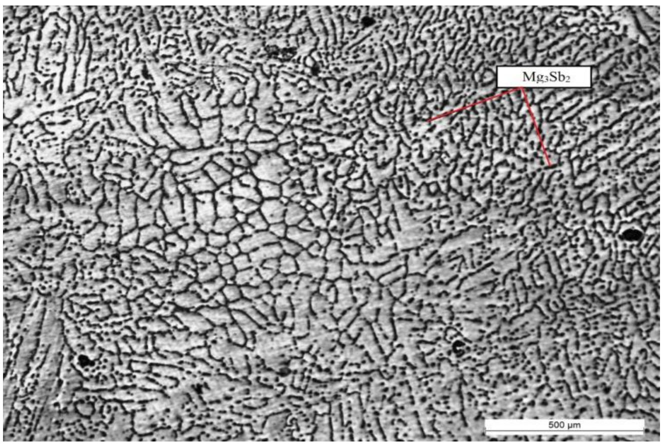

Fig.1:Microstructure of Mg-Sb binary alloy(Sb-2%)

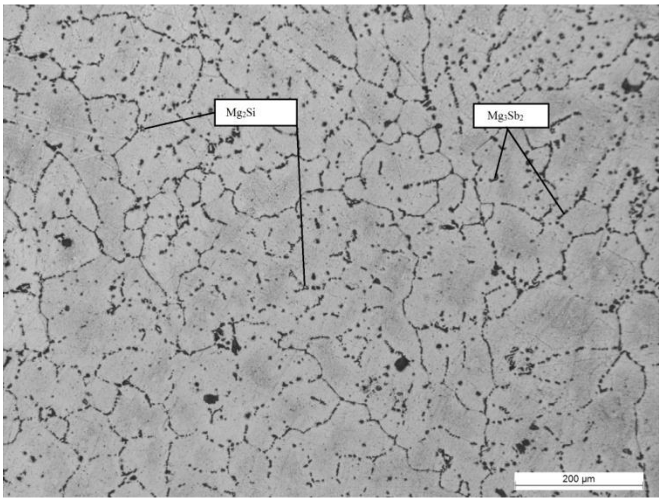

Fig-2:Microstructure of Mg-2%Sb-.5%Si ternary alloy

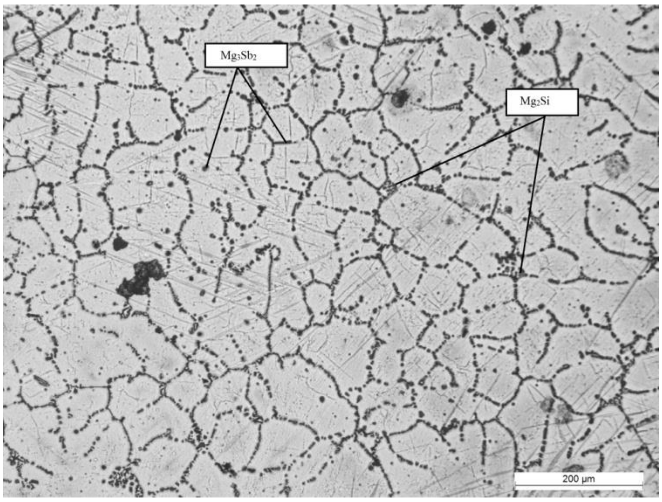

Fig-3: Microstructure of Mg-2%Sb-1%Si ternary alloy

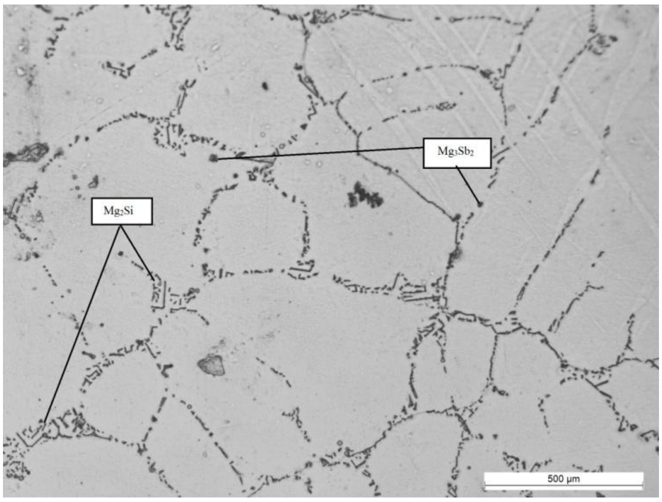

Fig-4:Microstructure of Mg-2%Sb-1%Si ternary alloy

Addition of Sb to Mg results in development of an intermetallic phase Mg_3Sb_2 which along the grain boundaries fig-1. From the microstructure it is clear that Mg_3Sb_2 is closely distributed in form of continuous precipitates. A new intermetallic phase Mg_2Si is formed at the grain boundaries when .5%Si is added to the Mg-Si binary alloy system fig-2. Mg_3Sb_2 phase acts as a nucleation centre for Mg_2Si particles. Mg_2Si is not distinctly visible at .5% Si addition. Silicon addition at about 1% refines the grain fig-3.The Mg_2Si in form of a Chinese script is visible at the grain boundaries. The optical results agress to have a balance between Mg_3Sb_2 and Mg_2Si at this addition. Further addition of silicon ie 2% results in formation of a much visible Chinese script shaped Mg_2Si phase fig-4.It is expected that the Silicon addition to Mg-Sb system will improve its mechanical properties.

2.1 Tensile Testing

The specimen for the tensile testing was machined as per ASTM standards. Four samples of tensile specimen were tested out from each set of casting.

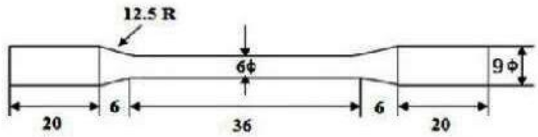

Fig-5: Tensile specimen (All dimensions are in mm)

Fig-6: Tensile testing in UTM

The tensile testing was conducted using ultimate tensile testing machine. Extensometer were connected to the specimens for measuring elongation.From the datas obtained from the tensile test(about 2000 datas per set). Stress-Strain Curve was plotted using Systat software. The stress-Strain curves for various alloying compositions is given below.

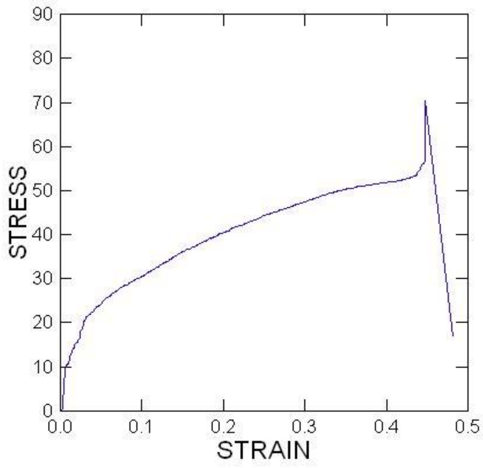

Fig-7: Stress (in MPa)-Strain curve(Mg-2%Sb)

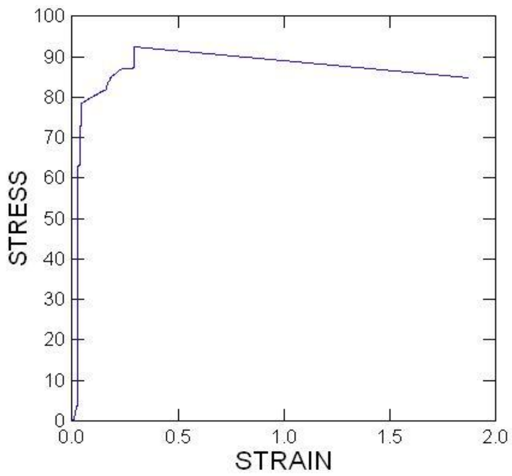

Fig-8:Stress(in Mpa)-Strain curve (Mg-2%Sb-.5%Si)

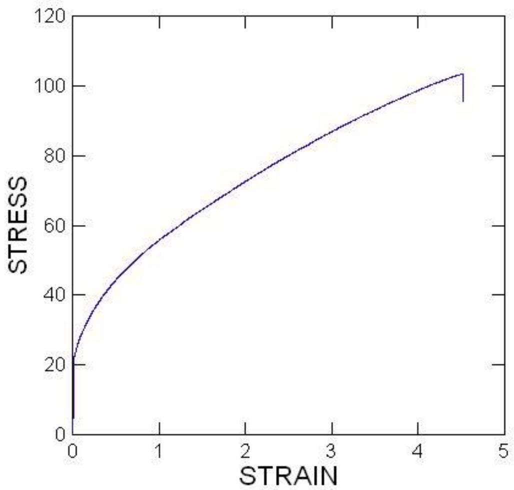

Fig-9: Stress(in Mpa)-Strain curve (Mg-2%Sb-1%Si)

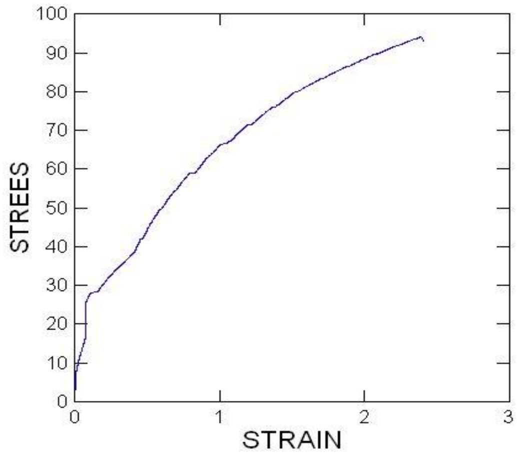

Fig-10: Stress-Strain Curve (Mg-2%Sb-2%Si)

Stress-strain graph indicates Mg-Sb binary alloy is having the least tensile strength of 72.41 MPa.Si addition improves the tensile strength of the alloy.Maximum tensile strength was found to be 103.48 MPa for 1% Si addition.Above 1% silicon addition tensile strength is significantly reduced.For Mg-Sb binary alloy the stress value was found to decrease steeply after reaching the maximum value whereas for .5% Si addition the stress value almost remains constant before failure.

2.2 Analysis of Necking Behaviour

During manufacturing process large amount of plastic strain accumulate in metals. Thus for accurate modelling of such processes we assume a large strain behaviour for a wide range of strain rates. In metals plasticity describes the deformation of material undergoing nonreversible change of shape in response to applied forces.Plasticity in metals developed due to the consequence of dislocations in the crystalline level. In the present analysis the material is assumed to undergo a nonlinear Isotropic hardening ie.the yield surface remains the same shape but expands with increasing stress. The plastic response is assumed to follow a non-linear Isotropic hardening model with yield stress given by

$$\sigma_{ys}=\sigma_{yso}+H\varepsilon_{pe}+(\sigma_{ysr}-\sigma_{yso})(1-e^{-\xi\varepsilon pc})$$

where
σ_{ys}= yield stress,
σ_{yso}= Initial yield stress
H=Linear hardening coefficient,
ε_{pe}=equivalent plastic strain
σ_{ysr}= the residual stress
,ξ=saturation exponent[5,6]

Double dogleg solver is employed for solving the problem.A two dimensional axisymmetric model of the specimen is modelled and plastic strains are calculated at various gauss points.A constant residual stress is assumed.Extremely fine triangular mesh is employed consideing the complexity of the problem.The hardenning coefficient values as well as saturation exponent values for various alloying combination are shown in the table 2.

Table.2: Linear hardening coefficient and saturation exponent values for various alloy composition.

Alloy composition	H(linear hardening coefficient)	ξ (Saturation exponent)
Mg-2%Sb	37.59	.636
Mg-2%Sb-.5%Si	116.32	.144
Mg-2%Sb-1%Si	53.64	.437
Mg-2%Sb-2%Si	64.95	.4909

2.3 Results and Discussion

The plastic strains is evaluated at various gauss points.A graph between neck radius vs top displacement was plotted.The results obtained are given below.

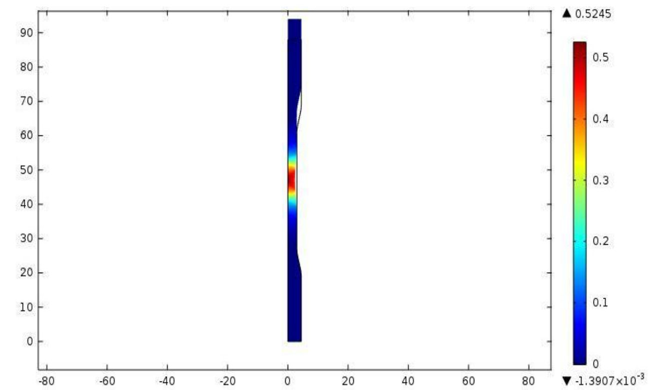

Fig-11: Plastic strain evaluated at various gauss points for(Mg-2%Sb alloy)

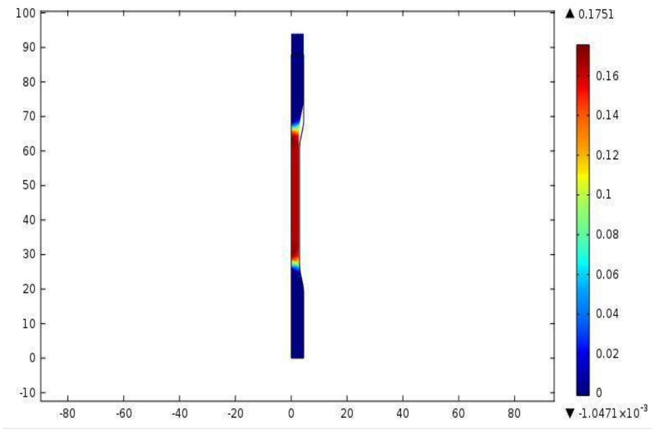

Fig-12: Plastic strain evaluated at various gauss points for Mg-2%Sb-Si(.5%,1%,2%)

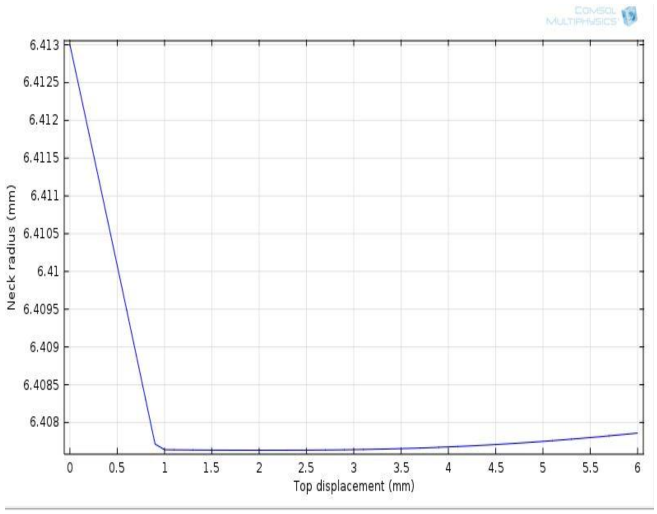

Fig-13: Neck radius vs top displacement (Mg-2%Sb)

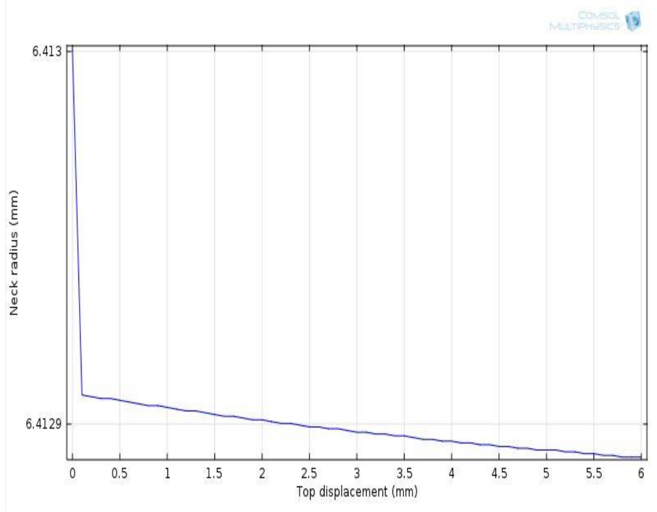

Fig-14 Neck radius vs top displacement (Mg-2%Sb-.5%Si)

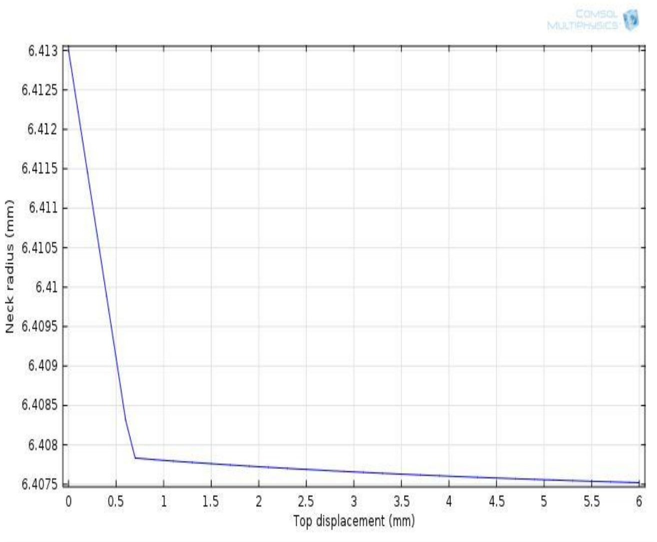

Fig-15: Neck radius vs top displacement (Mg-2%Sb-1%Si)

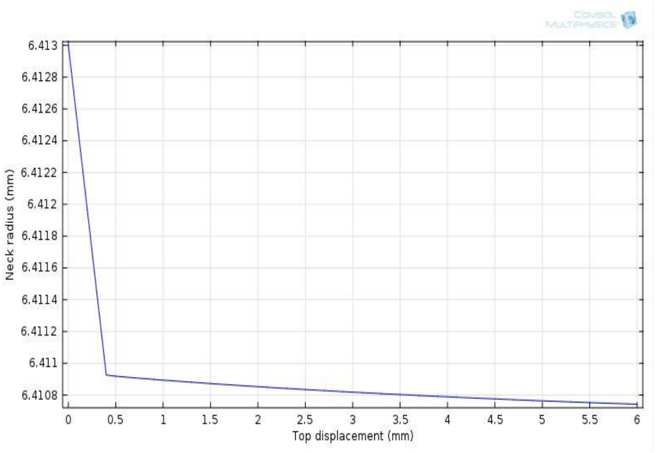

Fig-16: Neck radius vs top displacement (Mg-2%Sb-2%Si)

For Mg-Sb alloy the maximum value of plastic strain is nearly $.5*10^{-3}$ units Fig-11.By Silicon addition the plastic strain developed in the material is significantly reduced ie $.16*10^{-3}$ units Fig-12. Silicon added alloys irrespective of the composition shows a similar plastic strain distribution. The maximum plastic strain developed in the Mg-Sb binary alloy is at the midsection whereas the plastic strain is uniformly distributed along the gauge length in the case of Mg-Sb-Si ternary alloys. It can be inferred that the high hardness of the Mg_2Si intermetallics is responsible for the reduction in plastic strain and thereby providing the alloy a brittle nature. Mg_3Sb_2 intermetallics developed in form of continuous precipitates might be the reason for plastic behaviour of Mg-Sb binary alloys.Mg_3Sb_2 itself being an hard phase the plastic behaviour is not predominant.

The graph plotted between neck radius and top displacement indicates the plastic deformation occurs below 1mm top displacement. For Mg-Sb binary alloy the deformation occurs until .9mm top displacement where as for .5%Si added alloy failure takes place at .2 mm top displacement. For 1% Si addition plastic behaviour is significantly improved. At this addition there exist a balance between Mg_3Sb_2 and Mg_2Si intermetallics which might be the reason for improved tensile behavior of the alloy. For Mg-2%Sb-2%Si ternary alloy the plastic behaviour is further reduced. The increase in Chinese script shaped Mg_2Si intermetallics at the grain boundaries in form of discontinuous precipitates might be the reason for this which inturn reduces the tensile strength of the alloy.

3. CONCLUSIONS

1. Intermetallics play a vital role in morphological and mechanical properties of Mg alloys.
2. Mg_3Sb_2 phase in form of rod shaped continuos precipitates induces plasticity to the alloy.
3. Tensile strength of the alloy is improved by Si addition.For higher amount silicon addition the tensile strength is significantly reduced due to the presence of discontinuous Mg_2Si intermetallics.
4. Mg_2Si intermetallics inform of chinese script shape promotes brittle fracture.
5. Maximum plastic strain distribution is at the midsection for Mg-Sb binary alloy whereas for Mg-Sb-Si ternary alloy the plastic strain is constant throughout the entire gauge length.

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