ISSN 2249-5460

INTERNATIONAL JOURNAL OF MATHEMATICAL SCIENCES, TECHNOLOGY AND HUMANITIES

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International eJournals

International Journal of Mathematical Sciences, Technology and Humanities 68 (2012) 756 – 765

Material Characterization Of 6061 Al-Si Cp Metal Matrix Composites

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ABSTRACT

The unique tailorability of the composite materials for the specific requirements makes these materials more popular in a variety of applications such as aerospace, automotive (pistons, cylinder liners, bearings) and structural components, resulting in savings of material and energy. In this present work, the production and properties of Al 6061/SiC composites, made using stir casting method, are investigated. The specimens are made by liquid metallurgy route (bottom pouring) in mushy state with secondary processing method. The tensile properties and fracture mechanism of the cast material are experimentally studied. The influences of weight fraction of SiCp reinforcement on tensile strength and fracture toughness have been evaluated. The underlying mechanisms governing the fracture behavior during tensile and fracture toughness tests have been discussed. Also crack path morphology was studied to determine micro-mechanisms of failure and the influence of microstructure on crack growth characteristics. Tensile properties obtained by experimental results are compared with FEA results using ANSYS, commercial software.

Keywords: Aluminum MMC, Bottom pouring, secondary processing, fracture toughness.

1. INTRODUCTION

The unique tailorability of the composite materials for the specific requirements makes these materials more popular in a variety of applications such as aerospace, automotive (pistons, cylinder liners, bearings) and structural components, resulting in savings of material and energy , Taha, 2001; Allison and Cole, 1993 . In this paper, fabrication of 6061 Al/SiCp MMC by liquid metallurgy route (Bottom pouring) in mushy state, with secondary hot rolling is discussed. The Aim of the present study is to investigate and compare the tensile, fracture behavior and micro-mechanisms of failure in Al- 6061 unreinforced alloy and metal matrix composites.

MATERIAL and methods

Aluminum alloy AA 6061 T6 with composition (weight percent) Mg - 0.8-1.2, Si- 0.4-0.8, Cu-0.15-0.4, Mn- 0.15Max, Cr- 0.04-0.35 and Al- remainder is used as the base matrix. The dispersoids used are silicon carbide particles of sizes 5.7µm, 12.6µm and 18.15µm in 5%, 10% and 15% by weight.

3. PROCESSING OF MMC

Fig.1 (a-c) shows the schematic of rheocasting or stircasting (bottom pour) set up which was fabricated for the composite processing. About 2 kilograms of the AA 6061 alloy is cleaned and loaded in the silicon carbide crucible and heated to above its liquidus temperature. The temperature was recorded using chromel-alumel thermocouple. To maintain the solid fraction of about 0.4, the temperature of the melt was lowered before stirring. The specially designed mechanical graphite stirrer is introduced into the melt and stirred at ~ 400 rpm (Fig 2). The depth to which the impeller was immersed is approx 1/3rd the heights of the molten melt from the bottom of the crucible Aniban et al 2002 [3]. The preheated (8000C) SiC particulates (18.15µm) were added through a preheated pipe by manual tapping into the slurry, while it was being stirred. Table 1 gives the rheocasting details. A post-addition stirring time of 15 min was allowed to enhance the wetting of particulates by the metal. The temperature of the slurry was sufficiently raised above the melting range of the matrix alloy before pouring the composite melt into preheated permanent mould. Fig 3 shows as-cast MMC in different mould shapes to facilitate testing.

4. SECONDARY PROCESSING OR HOT ROLLING

The as-cast composite billets were hot rolled for (16 - 23 % reduction) at 400^{o}C for 1 hour and 45 minutes in order to get rid of the porosities induced during primary processing (Fig 4). It also improves the distribution of the reinforcement in the matrix. Secondary processing improves distribution of SiCP in the matrix, imparts directional properties, whereby mechanical properties are improved. Edge cracks in rolled billets were observed after final reduction during rolling. The Hot rolling details of Metal Matrix Composite (AA6061+SiCp) are shown in Table 2.

4. SPECIMEN PREPARATION

Round tensile specimen with the gauge diameter 4.5 ± 0.1 mm and gauge length of 17.5 mm as per BS-18, as shown in Fig 5 were used for tensile testing. The Compact Tension (CT)specimens for KIC and Fatigue Crack Growth Rate (FCGR) (da/dN) determination are prepared in LT direction with notch and intended direction perpendicular to the rolling direction as per ASTM E-1820 and ASTM E-647 standards as shown in Fig 6.

5. RESULTS AND DISCUSSION:

5.1 MICROSTRUCTURE

The optical micrograph of AA 6061 alloy and composites with 5%, 10% and 15% SiC particles in rolling direction are shown below in fig 7 (a-e). EDAX of 6061-alloy showed that there is a loss of Mg and Si content during stirring process of MMC processing.

5.2 FRACTURE TOUGHNESS TESTING

Plane strain fracture toughness (KIC) tests were conducted on BiSS 50 KN servo hydraulic Universal Testing Machine, using CTS as per ASTM E-1820. The conditional fracture toughness(Table 3) was calculated using following eqn.

$$K_Q = P_Q f(a/b)\, B.W^{1/2}$$

KQ = Conditional Fracture Toughness
B = Thickness of the specimen
W = Width of the specimen

5.3 TENSILE TESTING

The tensile properties such as 0.2% yield strength; ultimate tensile strength and percentage elongation have been evaluated for AA 6061 base alloy (T6), Annealed 6061 alloy and composites and are shown in Table 4

5.4 FRACTOGRAPHIC ANALYSES AND DISCUSSION

The fracture surfaces of AA-6061 unreinforced alloy and Al-6061/SiCp MMC (both in rolled condition), that failed during fracture toughness tests and tensile tests were investigated for identifying the micro mechanisms of failure (Fig 8 – 11). Samples after mechanical testing were cut to the specified dimensions and then ultrasonically cleaned in acetone and examined the fractured surfaces in ESEM at RSIC, IIT Bombay. AA 6061 alloy having mixed mode type of Lots of cracks are present with river line tensile fracture displaying complicated patterns, very few dimples are present. Array of facets and isolated dimples. Overall it is brittle fracture showing equiaxed Test for AA6061 Matrix alloy.

The presence of tear ridges in 15% SiCp MMC indicates that there is a constraints on the plastic flow of matrix imposed by SiC particles due to which the matrix in the interparticle regions undergoes extensive localized plastic strain, but on a macroscopic level the specimen fails in a brittle manner. The fractured particles as well as interface decohesion can induce voids in the matrix which may result in lower fracture toughness and tensile properties in 15% SiCp MMC.

5.5 MODELING THE UNIAXIAL TENSILE TEST IN ANSYS

The validation of material model should be carried out in simple reproducible that requires a low computational cost in FEA software. One material model validation should consist of modeling the same uni-axial tensile test from which the stress-strain data points have been recorded. A reproduction of the tensile test conditions in ANSYS are observed in following figures.

6. CONCLUSIONS

The mechanical properties of metal matrix composites after hot rolling were not significantly improved due to the presence of shrinkage cavities and particle cracking. Also it has been observed that there is a loss of Mg content during stirring of MMC fabrication and hence decrease in mechanical properties. The plane strain fracture toughness KIC of the MMC is observed to be comparable with unreinforced matrix alloy in annealed condition. Unreinforced alloys 6061 in rolled condition has high toughness and therefore, crack arrest capability. They may therefore, be considered as potential candidate materials for automobile and aerospace sectors where high strength with reduced weight and high crack arrest capabilities will contribute to crash worthy design of automobile/aircraft structures. One can optimally exploit the properties of such materials by making Metal Matrix Composites with proper choice of secondary process for better life of the component.

References:-

1. Taha, A.M., 2001. Practicalization of Cast Metal Matrix Composites (MMCCs). Materials and Design, Vol. 22 (2001) pp 431- 441.
2. Allison, J.E. and G.S. Cole, 1993. Metal-matrix composites in the automotive industry: Opportunities and challenges. JOM, Vol.45, No. 1 (1993), pp. 19-24.
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Table.1 Rheocasting Details of MMC

S.No.	Composite system	SiCp Size (μm)	Preheat Temp of SiCP	Total Stirring time	Pouring Temp. ($0\,^{o}C$)
1.	6061+5% SiCp (wt%)	18.15	800^0C	15min	730
2.	6061+10% SiCp (wt%)	18.15	800^0C	15min	700

3.	6061+15% SiCp (wt%)	18.15	800^0C	15min	633

Table.2 Hot Rolling Details of MMC

S.No	Matrix + SiCp (wt%)	Size of SiCp (µm)	Thickness (mm) (In 15 Passes)		Percentage Reduction %
			Before Rolling	After Rolling	
1	6061+ 5% SiCp	18.15	21	16	23
2	6061+10% SiCp	18.15	24.5	20.5	16
3	6061+ 15% SiCp	18.15	20	16.5	18
4	6061+ 0% SiCp	--	20.5	16	22

Table 3: Fracture Toughness results of base matrix and Composite

Composite System	B(mm)	W(mm)	$\frac{a}{w}$	f (a/w)	PQ (KN)	KQ Mpa√m
AA 6061 + 0% SiCp	12.5	50	0.51	10.02	3.24	KQ= 11.64
6061 + 5% SiCp (18µm)	9	36	0.5	9.61	---	KQ ~ 9.8

Table 4: Tensile Properties

Condition (Rolled)	%Elongation	0.2% Y.S (Mpa)	UTS (Mpa)
AA6061 (T6)	22	289.91	328.5
AA6061 (Annealed) + 0% wt. SiCp	35	56.12	135.6
AA 6061 + 5% wt. SiCp (18µm)	1.8	52.1	52.8
AA 6061 + 10% wt. SiCp (18µm)	1.2	40	40.5
AA 6061 + 15% wt. SiCp (18µm)	0.4	50	53.4


Figure. 1(a) shows the schematic of rheocasting or stircasting setup (bottom pour), (b) Graphite stopper for bottom pour arrangement

Fig 1(c): Shows Bottom pour facility in SiC crucible

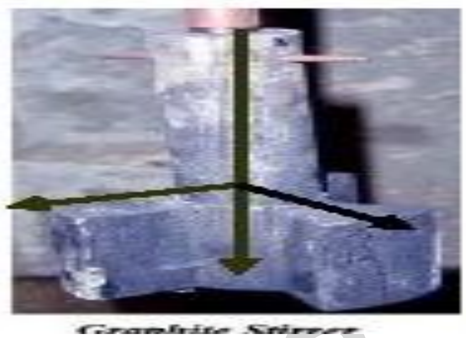


Fig.2: Graphite stirrer

Fig 3: shows as-cast MMC in different mould shapes to facilitate

Fig 4: As-cast Composite Rolled Billets

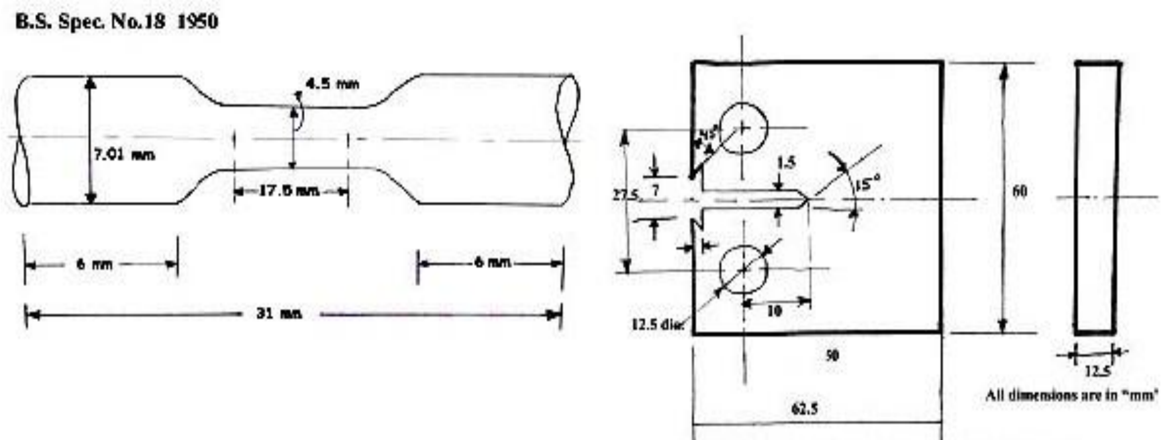
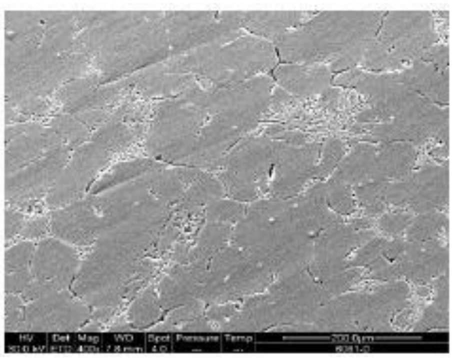
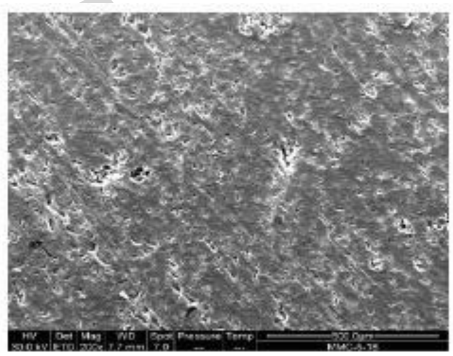


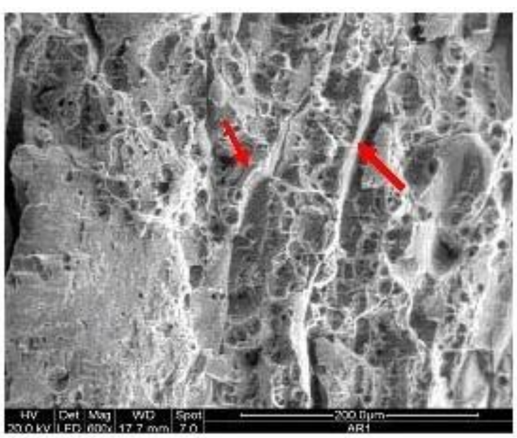
Fig : FCGR Test Specimen (ASTM E 647)

Fig: 5 and6 Tensile Specimen and Compact Tension (CT) specimens for KIC and FCGR determination respectively





(a) AA 6061 (x 400) (b) AA 6061 / 5% wt SiCp / 18µm (x200)



(c) AA 6061 / 10% wt SiCp / 18µm (x200) (d) AA 6061 / 15% wt SiCp / 18µm (x200)
Fig 7 (a-e) optical micrographs of (a) AA6061 (b) 5%wt SiCp (c) 10%wt SiCp (d)

15%SiCp Composites (e) EDAX of AA 6061 alloy showing the loss of Mg and Si Content during stirring process.

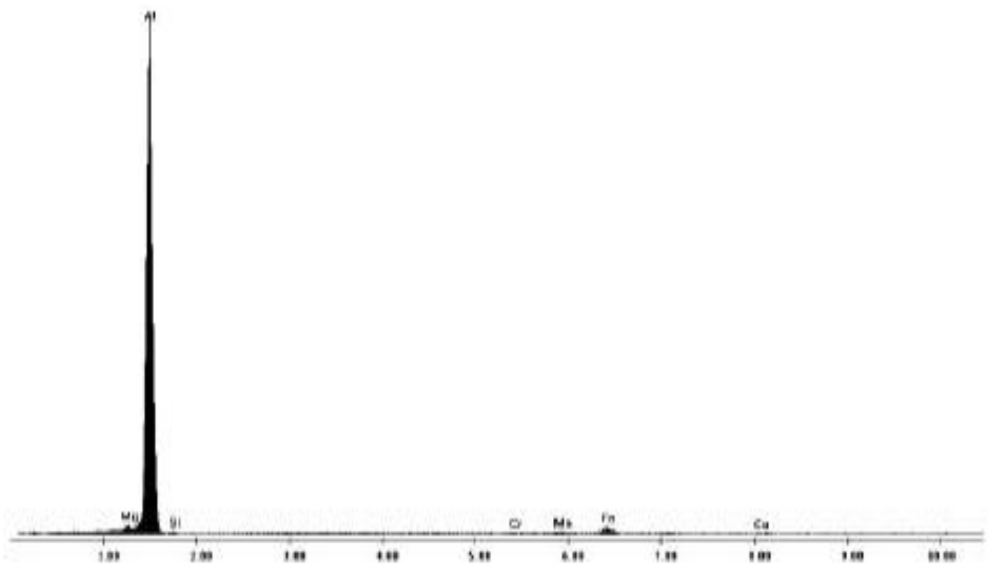
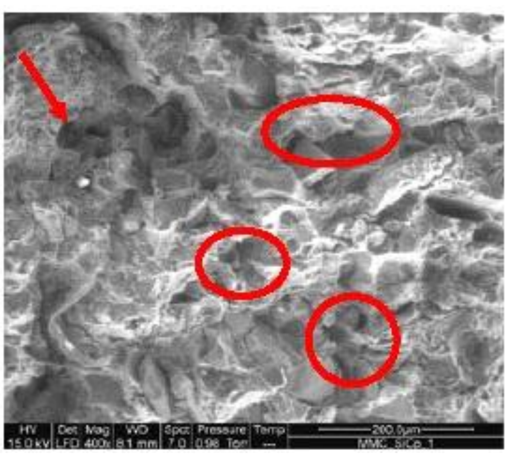


Fig 8: Tensile Fractographs for AA6061 Matrix alloy



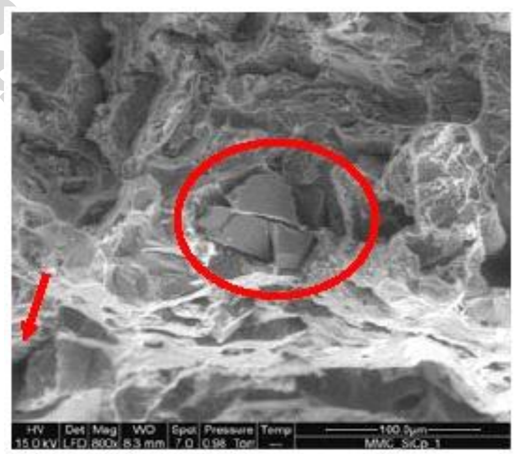
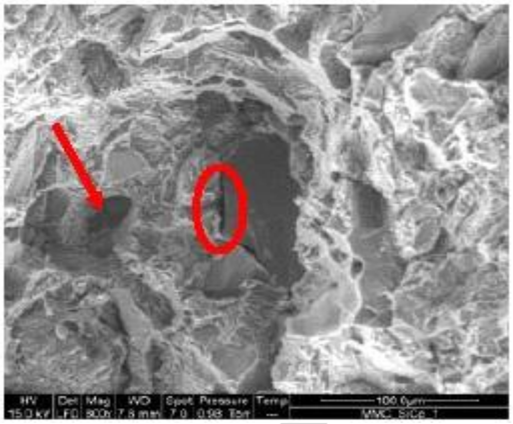
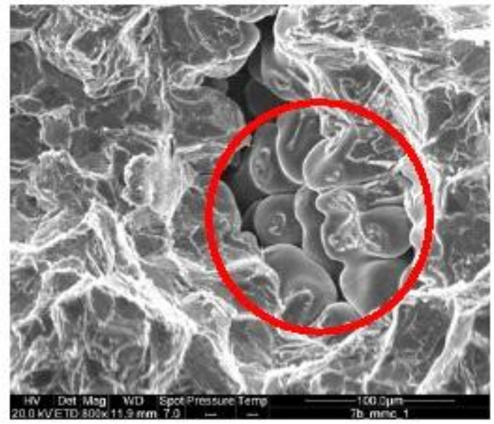


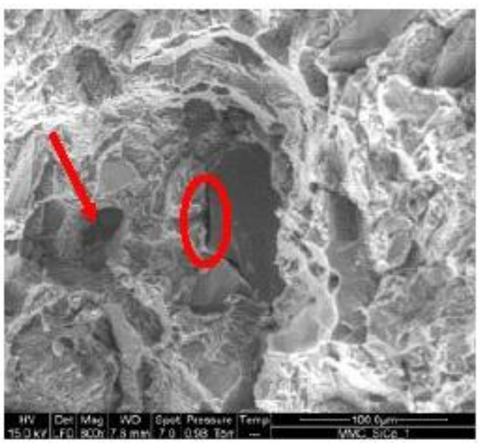
Fig 9: Brittle striations with Internal **Fig 10: AA6061 Matrix alloy**
(Cracks and river lines are present in KIC region in KIC Test)



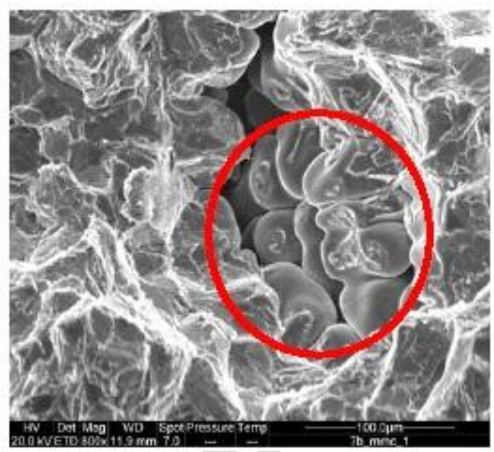
5% SiCp shows dimples, less in number and shallower when compared to matrix alloy (Fig8). Mainly the mode of failure here is VNG along particle interface.



With 10% SiCp, the mode of fracture is mainly interface debonding and particle fraction. Some porosity is also observed due to less %age reduction in rolling.



With 15% SiCp, fraction of dimples decreases with increasing SiC content and hence reduced plastic strain. Particle matrix interface decohesion along with some tear ridges is observed in the matrix region.



Hot rolling of MMC causes coarse dendritic cell structure displaying shrinkage cavities. These cavities are formed due to SiC particles.
This type of failure is a brittle failure.

Fig 11 (a-d): Tensile Fractographs of AA6061/SiCp MMCs (a) 5% SiCp (b) 10% SiCp (c) 15% SiCp (d) hot rolling

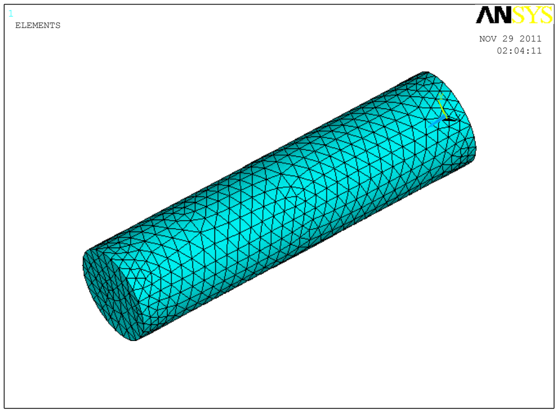


Fig 12 a test model

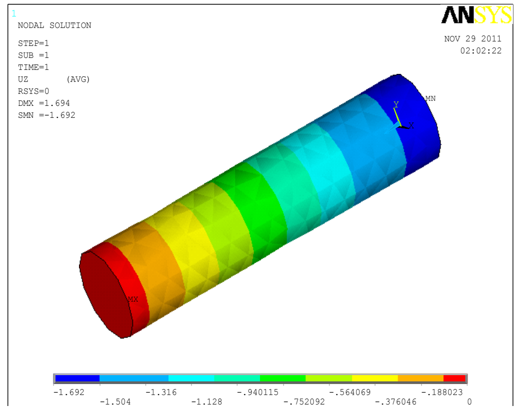


Fig 12 b load 1 result

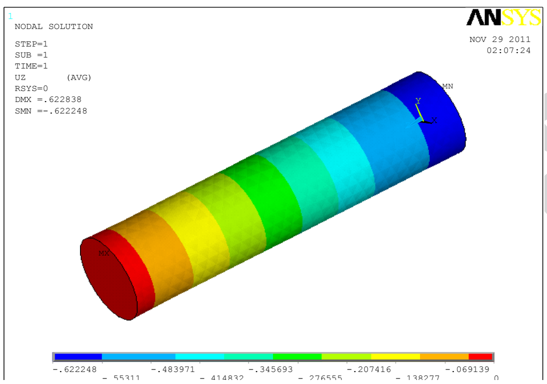


Fig 12 c load 2 result

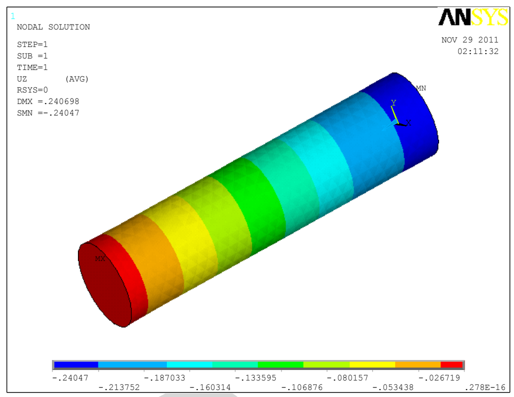


Fig 12 d load 3 result

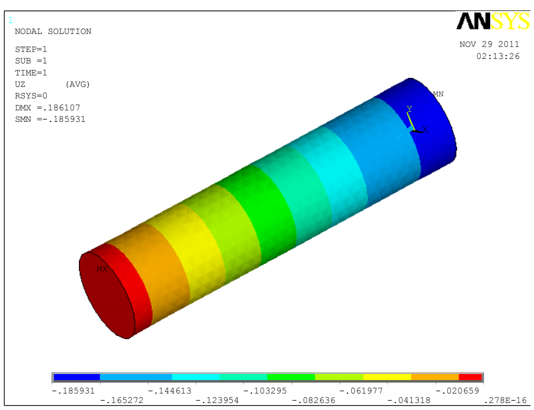


Fig 12 e load 4 result

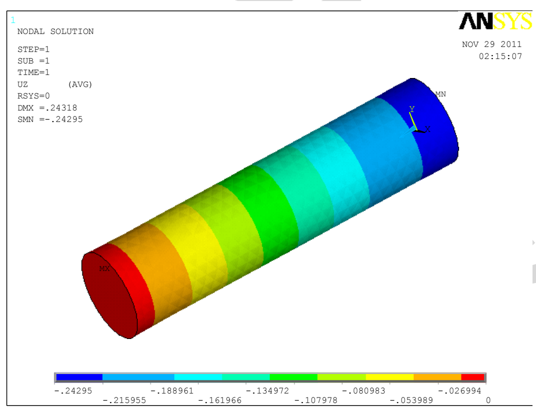


Fig 12 f load 5 result