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Fracture Analysis of FDM Manufactured Acrylonitrile Butadiene Styrene Using Fem

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Abstract: **The research paper gives the study about the fracture behavior of the rapid prototyping polymer material- Acrylonitrile Butadiene Styrene (ABS). The present work is performed for fracture analysis with experimental as well as finite element method. In this research, 9 specimens of ABS was produced by FDM technique, all of having different crack length and infill (parameter of FDM). The shape & size of specimen is selected as per ASTM D 5045. Experiment for fracture testing is conducted to measure stress intensity factor (SIF) and crack mouth opening displacement (CMOD) for each & every specimen. Then fracture analysis have been done in FEM software- ANSYS and the comparison have been done for both results data for analysis.**

Keywords: **Fracture analysis, FDM, ABS, Crack mouth opening displacement, FEM**

I. INTRODUCTION

The theory of fracture is of central importance in the design of engineering structures. Fracture mechanics is based on the implicit assumptions that there exists a crack in a work component. In today's growing need to solve the complexities in manufacturing the complex structures, the need for rapid prototyping is increasingly growing. Method of Rapid Prototyping (RP) is most commonly used for rapid production of new part intended for presentation purposes. There is number of specific methods used in area of RP: Stereo lithography (SLA), Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM), Fused Deposition Modelling (FDM), Solid Imaging (SI) or Multi-jet Modelling, 3D Printing (3DP) or Selective Binding, Laser Engineering Net Shaping (LENS). Among all these techniques of RP, Fused Deposition Modelling is widely used in industry. In FDM technique, the material used to make prototypes are polymer. Fused Deposition Modeling is one of the typical RP processes that provide functional prototypes of ABS plastic. FDM produces the highest-quality parts in Acrylonitrile Butadiene Styrene (ABS) which is a common end-use engineering material that allows you to perform functional tests on sample parts. The toughness of a polymer is described as the ability to resist fracture by absorbing energy and is therefore a very important material property. Much research in the polymer field aims at improving the toughness of a material and investigates the mechanisms by which such an improvement can be obtained. The present topic describes the fracture behavior of FDM material- ABS with experimental testing of fracture property and comparing the result with FEM results.

Fracture Mechanics: There are two steps in fracture- Crack formation & crack propagation. The fracture is termed ductile or brittle depending on whether the elongation is large or small. There are three modes of fracture: Mode I is opening mode, mode II is sliding mode & mode III is tearing mode. The analysis of fracture mechanics problem is done through different approaches, each having its own parameter. All of them are well accepted to measure the potency of a crack; only one is needed to solve a problem. The parameter Energy Release Rate (G) is energy based and is applied to brittle or less ductile materials. Stress Intensity Factor (K) is stress based, also developed for brittle or less ductile materials. J-Integral (J) has been developed to deal with ductile materials. Crack Tip Opening Displacement (CTOD) parameter has been also developed for ductile materials and it is displacement based. [1]

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Fused Deposition Modelling: Fused Deposition Modelling (FDM) was developed by Stratasys in Eden Prairie, Minnesota. Fused deposition modeling (FDM) uses heated thermoplastic filament which are extruded from the tip of nozzle in a prescribed manner in a temperature controlled environment for building the part through a layer by layer deposition method. Common materials used in FDM are: ABS, PC, PC-ABS, PPSF/PPSU, Ultem-9085 etc. [2]

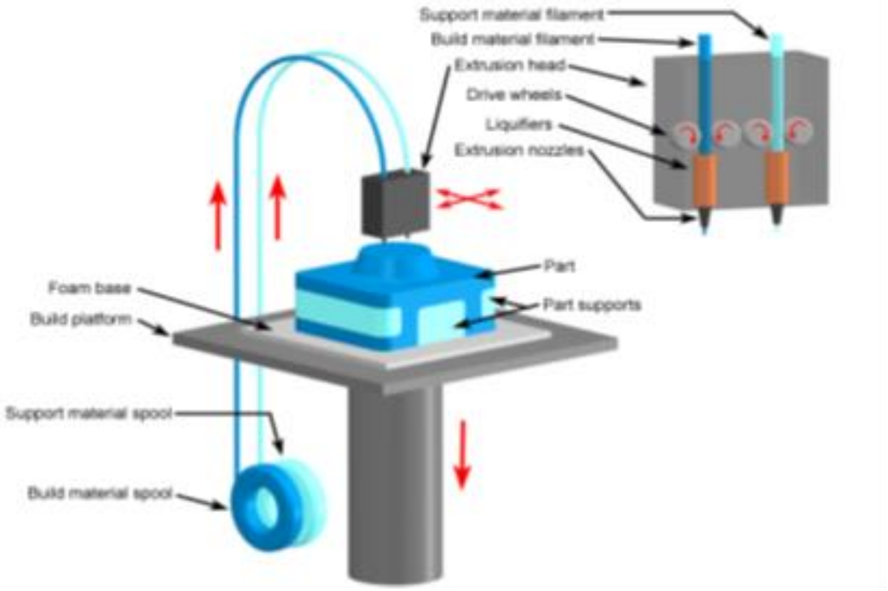

Fig.1 Fused deposition Modelling process [2]

Acrylonitrile Butadiene Styrene: Acrylonitrile butadiene styrene (ABS) (chemical formula $(C_8H_8)_x \cdot (C_4H_6)_y \cdot (C_3H_3N)_z$) is a common thermoplastic. Its glass transition temperature is approximately 105 °C (221 °F). ABS is amorphous and therefore has no true melting point. ABS is a terpolymer made by polymerizing styrene and acrylonitrile in the presence of polybutadiene. The proportions can vary from 15 to 35% acrylonitrile, 5 to 30% butadiene and 40 to 60% styrene. For the majority of applications, ABS can be used between −20 and 80 °C (−4 and 176 °F) as its mechanical properties vary with temperature. The properties are created by rubber toughening, where fine particles of elastomer are distributed throughout the rigid matrix. [3]

Finite Element Method: The finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations. It uses subdivision of a whole problem domain into simpler parts, called finite elements, and variational methods from the calculus of variations to solve the problem by minimizing an associated error function. Analogous to the idea that connecting many tiny straight lines can approximate a larger circle, FEM encompasses methods for connecting many simple element equations over many small subdomains, named finite elements, to approximate a more complex equation over a larger domain.

II. LITERATURE REVIEW

A Literature Review is mainly carried out to know the fracture behavior in various conditions with experimental as well as FEM analysis of FDM manufactured Acrylonitrile Butadiene Styrene.

Ming-Luen Lu and Feng Chih-Chang has done the research work on Fracture toughness of a polycarbonate/acrylonitrile-butadiene-styrene blend by the ASTM E813 and hysteresis energy J integral methods: effect of specimen thickness and side groove. The outcome shows that the critical J values for specimens with V-shaped side grooves are higher than those without the grooves for thinner specimens, but the difference decreases with an increase in the specimen thickness. [4]

Dario Croccolo, Massimiliano De Agostinis, Giorgio Olmi has done the research work on Experimental characterization and analytical modelling of the mechanical behaviour of fused deposition processed parts made of ABS-M30. The study of the effects generated by the Fused Deposition Modelling production parameters on the tensile strength and on the stiffness of the generated components has been studied. The result shows that the effectiveness of the theoretical model has been verified by comparison to a significant number of experimental results, with mean errors of about 4%. [5]

John Lee and Adam Huang has done the research work on Fatigue analysis of FDM materials. FDM dog bones were tested at 100, 80, 60, and 40 percent nominal values of the ultimate stress for nine different print orientations. The result shows that for ABS printed parts strain energy ranged from 3.4 to 19.7 percent of the ABS material and ABS plus printed parts strain energy ranged from 1.8 to 7.4 percent of the ABS plus material. [6]

Eric Fodran, Martin Koch and Unny Menon has done the research work on Mechanical & Dimensional Characteristics of Fused Deposition Modeling Build Styles. Parameters such as fill gap, line width, and slice thickness were varied in the production of the FDM samples. The result shows that the mechanical properties of FDM modeled samples can be manipulated by the standard in which they are built. The properties can easily be altered by the modification of one of the criterion of FDM construction. [7]

III. INPUT/OUTPUT PARAMETERS

Input parameter: Crack length & Infill (FDM m/c parameter which shows the percentage of material in specimen).

Output parameters: Stress intensity factor & Crack mouth opening displacement.

Total 9 specimens are manufactured. Three crack lengths are taken as 28mm, 30mm, 32mm and three infill parameters are selected as 60%, 70% and 80%.

The input values of the production parameters of FDM machine are as follows: Layer thickness= 100 microns, Angle of orientation of FDM build style= 0°, Infill is taken as variable parameter and three different values are taken as 60%, 70% and 80%.

IV. MATERIAL

ABS (Acrylonitrile Butadiene Styrene) 1.75mm light blue spooled material was used for making specimens. Support material used in making of specimen was also ABS.

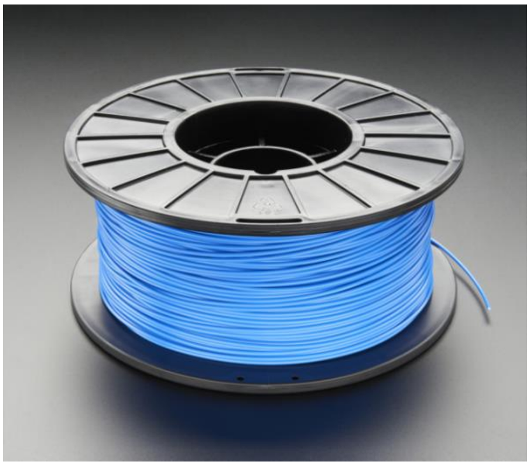

Fig.2 ABS light blue spooled material

Table.1 ABS material specification [3]

Material	ABS
Density	1.04 g/cc
Tensile strength, Yield	42.5 - 44.8 MPa
Maximum Service Temperature, Air	88 - 89 °C
Poisson's Ratio	0.35
Thermal Conductivity	0.2 W/m°C
Melting temperature	Amorphous, no 'true' melting point
Glass transition temperature	105°C (221°F)
Nozzle temperature	230°C (446°F)

V. MODELLING OF SPECIMEN

The detailed drawing of ABS specimens are as shown in figure. For every specimens, crack lengths are different. There are three different crack lengths are taken as max 32 mm, min 28 mm and average of 30 mm according to the ASTM D 5045. [8] Modelling was done with cross-section width of 60mm of every specimens.

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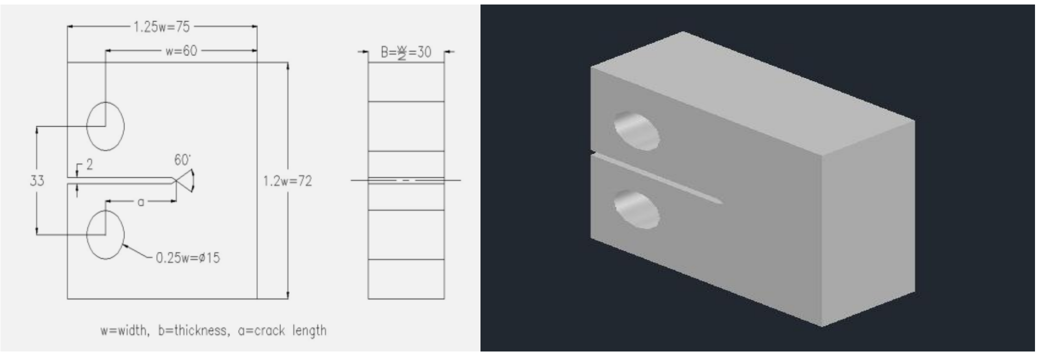


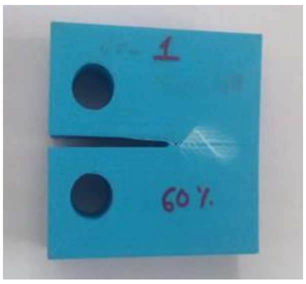
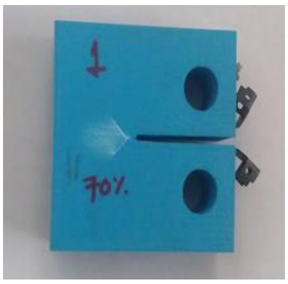
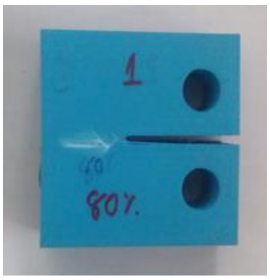
Fig.3 Model of specimen

VI. EXPERIMENTAL SET-UP

Experiment for fracture testing was done on Digital Universal Testing Machine which is available at Sankalchand Patel College of Engineering, Visnagar. Testing was performed by increasing the load at constant speed of 5mm/min.

Fig.4 Universal testing machine

Following are the photographs of the fractured specimens after testing:

		
(i) Crack length= 28mm Infill=60%	(ii) Crack length= 28mm Infill=70%	(iii) Crack length= 28mm Infill=80%

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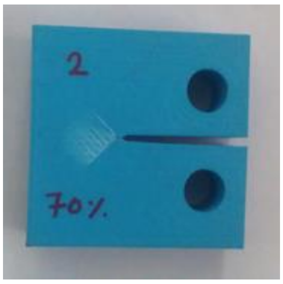
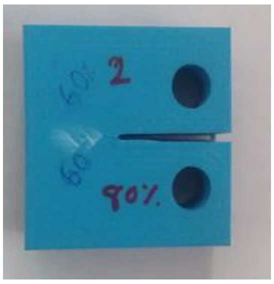
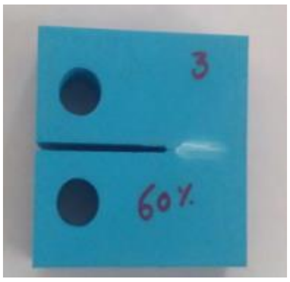
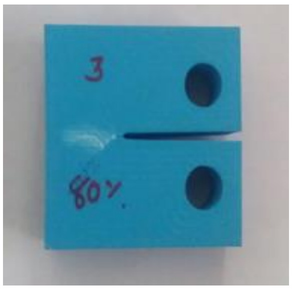
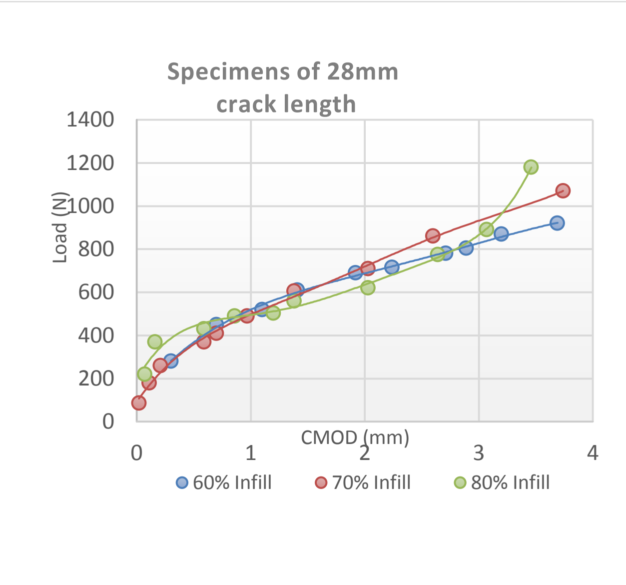
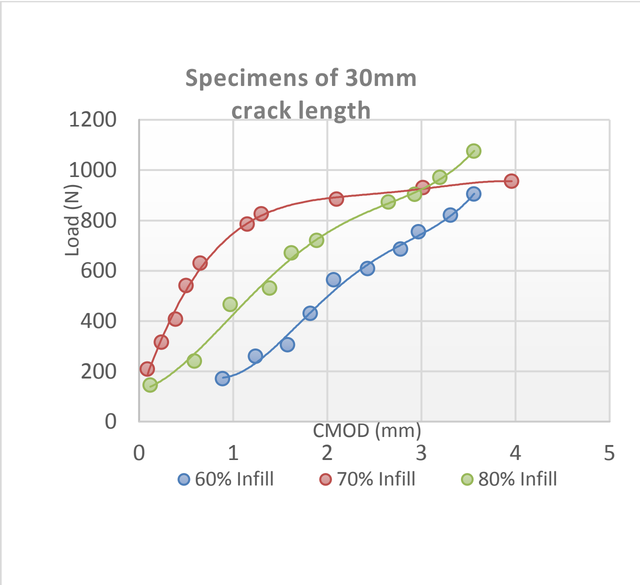
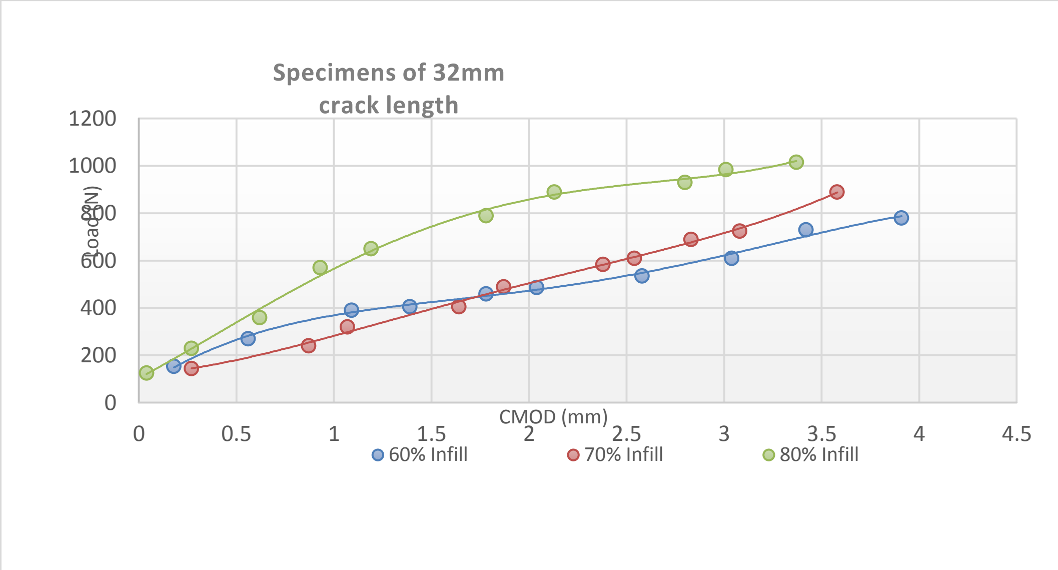
		
(iv) Crack length= 30mm Infill=60%	(v) Crack length= 30mm Infill=70%	(vi) Crack length= 30mm Infill=80%
		
(vii) Crack length= 30mm Infill=60%	(viii) Crack length= 30mm Infill=70%	(ix) Crack length= 30mm Infill=80%

VII. RESULTS AND DISCUSSION

Experimental result: From the experiment, CMOD (crack mouth opening displacement) and SIF (stress intensity factor) on different load are measured. Comparison of Load vs CMOD graphs of crack length with different infill are as follows.







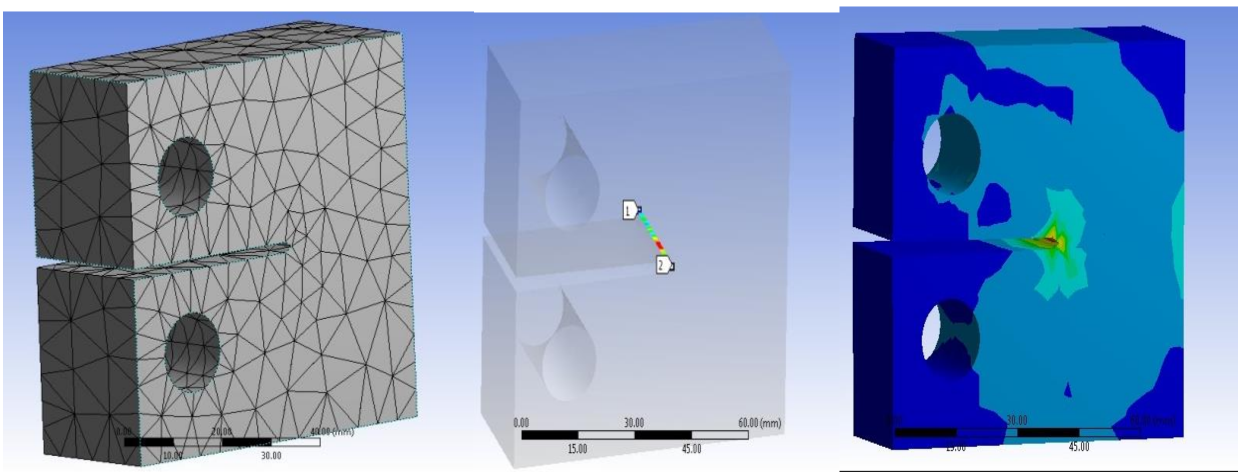
Following are the max. Values for different specimens:

Max. value of Load for different specimens			
Infill	**Crack length**		
	28mm	**30mm**	**32mm**
60%	920N	904N	780N
70%	1070N	955N	890N
80%	1180N	1075N	1015N

Max. value of SIF for different specimens			
Infill	**Crack length**		
	28mm	**30mm**	**32mm**
60%	34.654N√mm	37.575N√mm	36.019N√mm
70%	40.304N√mm	39.695N√mm	41.099N√mm
80%	44.447N√mm	44.683N√mm	46.872N√mm

FEM results: Fracture analysis has been performed on Ansys Workbench 14.5. FEM results for three specimens of different crack length are as follows.

	Crack length		
	28mm	**30mm**	**32mm**
Max. value of SIF	51.506N√mm (L=1367.41N)	55.51N√mm (L=1335.47N)	54.972N√mm (L=1190.41N)



(a) Mesh **(b) SIF** **(c) Stressed**

Fig. 5 Specimen model in ANSYS results

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VIII. CONCLUSION

From the experimental results, it was concluded that as infill increases, maximum load taken for fracture of specimen increases and SIF also increases. For gradual increase in crack length, max. load requirement for fracture of specimen decreases. From the FEM results it was found that the max. load required for fracture is decreases as crack length increases but same as experimental results, SIF value is variable in nature.

In experimental results, analysis have been done on infill and crack length parameter and in FEM, analysis have been done on crack length parameter as the specimen taken was solid. By comparing both the results, it was found that as the percentage of material increases, maximum load required for fracture is also increases.

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