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Experimental Investigation of Fracture of ABS Material by ASTM D-5045 for Different Crack Length & Layer of Orientation Using FDM Process

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Abstract: **The present work dedicated to experimental investigation of fracture of Acrylonitrile Butadiene Styrene (ABS) by ASTM D-5045 for different crack length & layer of orientation using fused deposition modeling (FDM) process. Objective of this work is to printing of Compact Tension (CT) specimen with different crack length and Layer of orientation by FDM process & printed Specimens are fractured in tensile machine for each & every cases. Result of experiment compered and data are analyzed for finding Stress Intensity Factor (K_I) and Crack Mouth opening and displacement (CMOD).**

Keywords: **Fracture, FDM, ABS, SIF, CMOD.**

I. INTRODUCTION

In order to create the new design, we need to take the failure and risks of the materials into consideration. In order to that, we need to study the material properties, its advantages and limitations. We need to study the failure criteria of the material and finding out its best operating life in various operating condition. In order to design the complex engineering structures and parts, the risk of making direct complex structure is high in order of taking finance and money into consideration. So the solution of this risk is making prototypes by additive manufacturing. In today's growing need of creating new design and technology, additive manufacturing is more developed and widely accepted idea.

Fracture mechanics: The aim of fracture mechanics is 'design to prevent structural failure'. There are mainly two types of fracture- Brittle fracture (Crack moves easily through components made of such materials) and Ductile fracture (fracture growth occurs due to substantial plastic deformation and creation of micro voids in the vicinity of the crack tip). There are three modes of fracture: Mode I (Opening mode), Mode II (Sliding mode) & Mode III (Tearing mode).[1]

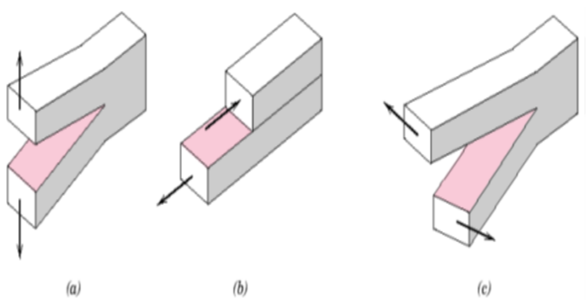


Fig 1 Modes of fracture

Fused deposition modelling: A plastic filament is unwound from a coil and supplies material to an extrusion nozzle. The nozzle is heated to melt the plastic and has a mechanism which allows the flow of the melted plastic to be turned on and off. The nozzle is mounted to an X-Y plotter type mechanism which traces out the part contours, There is a second extrusion nozzle for the support material (different from the model material). As the nozzle is moved over the table in the required geometry, it deposits a thin bead of extruded plastic to form each layer. The plastic hardens immediately after being squirted from the nozzle and bonds to the layer below. [2]

Materials used in FDM are: ABS-M30, ABS, PC (Polycarbonate), PC-ABS, PPSF/PPSU (polyphenylsulfone) and ULTEM 9085. In general, there are mainly two types of materials are used in FDM- ABS (Acrylonitrile Butadiene Styrene) and PC (Polycarbonate). Both these materials' blend (PC-ABS) also makes suitable properties for FDM which is used in certain applications.

Acrylonitrile Butadiene Styrene: Acrylonitrile butadiene styrene (ABS) (chemical formula (C8H8)x•(C4H6)y•(C3H3N)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. ABS is tough and strong over the recommended temperature range of -30°C to +60°C. [3]

II. LITERATURE REVIEW

This includes the latest studies on the analysis of Fracture behaviour of ABS using experimental methods and using the FEM. A review of previous work highlight some of the drawbacks and challenges.

Ming-Luen Lu and Feng Chih-Chang has investigated a non-conventional J integral based on hysteresis energy and the ASTM E813 methods were employed to test the fracture toughness of a polycarbonate (PC)/acrylonitrile butadiene-styrene (ABS) blend. The results show 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]

J. Martínez, J.L. Diéguez, E. Ares, A. Pereira, P. Hernández, J.A. Pérez has investigated with applying the methodology of making numerical simulations of two different composite structures with a ply-level approach and analyze obtained results. In this approach continuous ABS fibers with two different directional properties are to be taken into consideration. The result shows that the type of ply failure is determined by the load case, so if the ply is loaded by tensile stresses in the wire direction, normally the failure will be fiber dominated (rupture of the fiber). [5]

Francesco Baldi*, Silvia Agnelli, Theonis Riccò has investigated the application of an experimental approach based on the load separation criterion for the determination of the point of fracture initiation in a fracture test on a ductile polymer was critically examined and different levels of crack extension were produced. The result shows that -fracture initiation was a progressive process. [6]

P. Luna, C. Bernal, A. Cisilino, P. Frontini, B. Cotterell, Y.-W. Mai has investigated on the applicability of the EWF methodology to 3-point bend (SEB) specimens under conditions other than plane stress assessed experimentally. The results shows that the experiments conducted at room temperature, crack growth was observed to initiate before maximum load and complete ligament yielding. [7]

H. J. Kwon, P.-Y. B. Jar, Z. Xia has investigated toughness variation of non-notched poly (acrylonitrile-butadiene-styrene) (ABS) subjected to uniaxial fatigue loading. The test results showed that the fatigue loading caused the toughness drop in ABS, even before any visible crack was developed. [8]

III. EXPERIMENTAL WORK

I/O parameters: Input parameters are crack length and angle of orientation of FDM build style. There are three crack lengths and three angle are selected for preparing the specimen as follows:

Crack length (mm)	23	25	27	23	25	27	23	25	27
Angle of orientation (degree)	Flat	Flat	Flat	Edge	Edge	Edge	Up	Up	Up

Output parameters are Stress intensity factor (SIF) and Crack mouth opening displacement (CMOD).

Material: ABS (Acrylonitrile Butadiene Styrene) 1.75mm grey spooled material is used. Support material used is also ABS. Specifications of ABS are as follows: [3]

Material	ABS
Density	1.04 g/cc
Tensile strength, yield	42.5 - 44.8 MPa
Max. service temp., Air	88 - 89 °C
Poisson's Ratio	0.35
Thermal Conductivity	0.2 W/m°C
Melting temperature	Amorphous, no 'true' melting point

Modelling: The model of specimen is prepared in ABAQUS software. The crack length & notch configuration of specimen is taken as per ASTM D-5045. [9] The crack length (total length of the crack starter configuration plus the fatigue crack) should be between 0.45 to 0.55w for SIF determination.

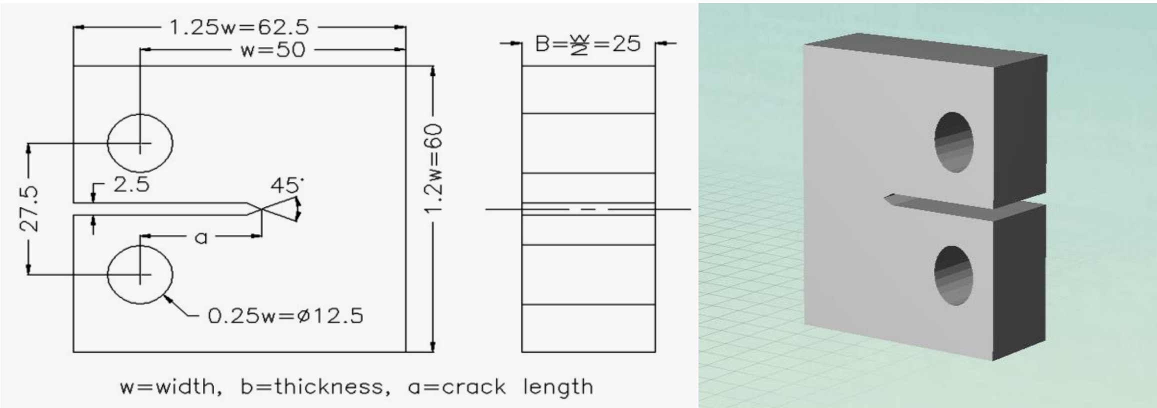


Fig 2 Model of specimen

Printing of specimen was done on Makerbot Replicator 2X model of FDM machine.

Fracture testing of specimen was done on Universal testing machine at MIT, Piludara by increasing the load at constant speed of 5mm/min.

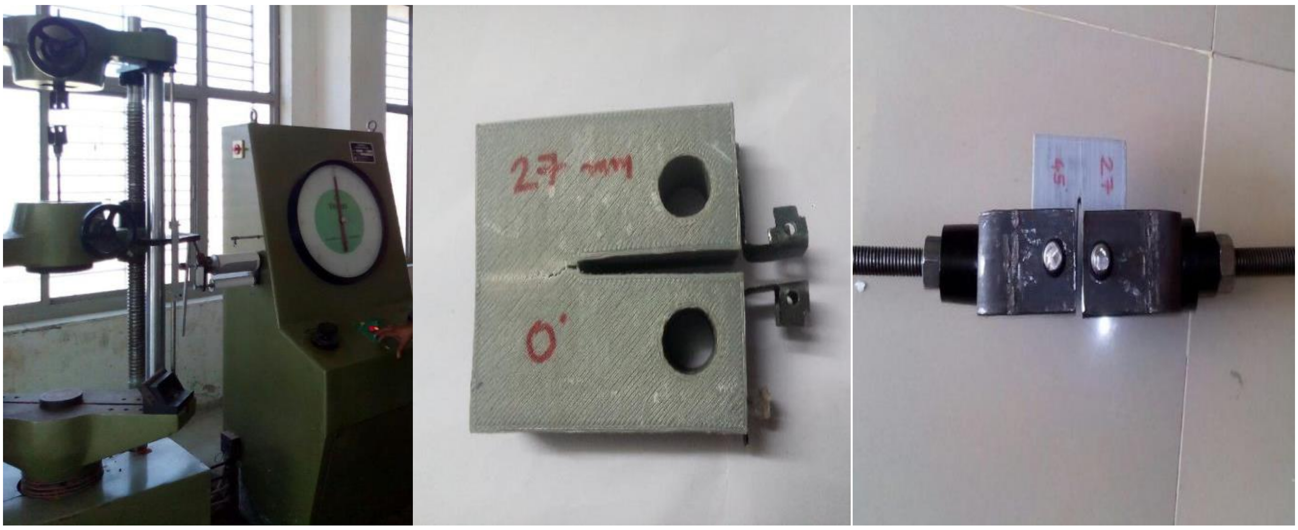
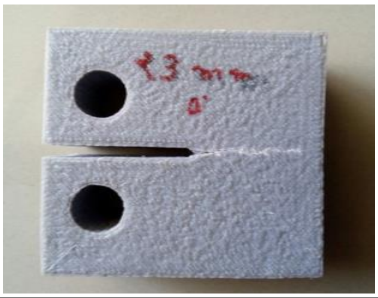
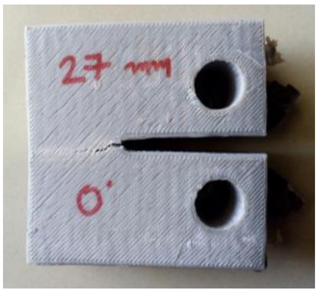
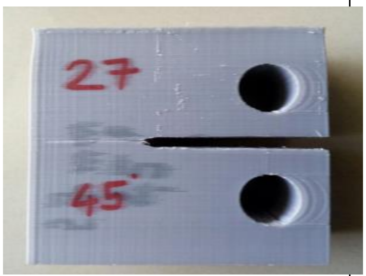
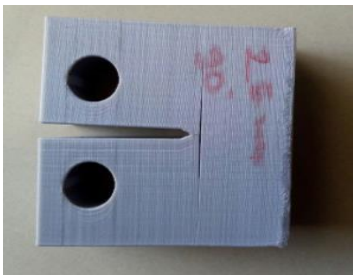
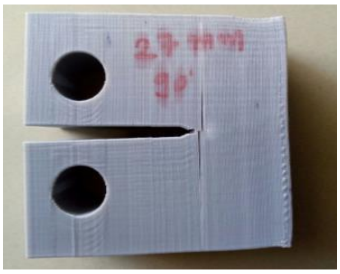


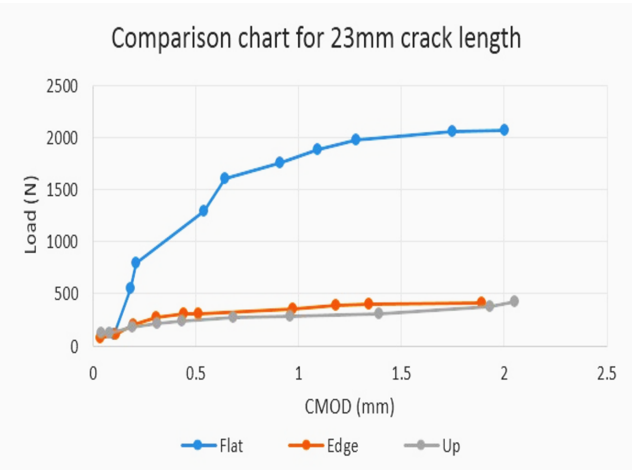
Fig 3 Experimental set-up

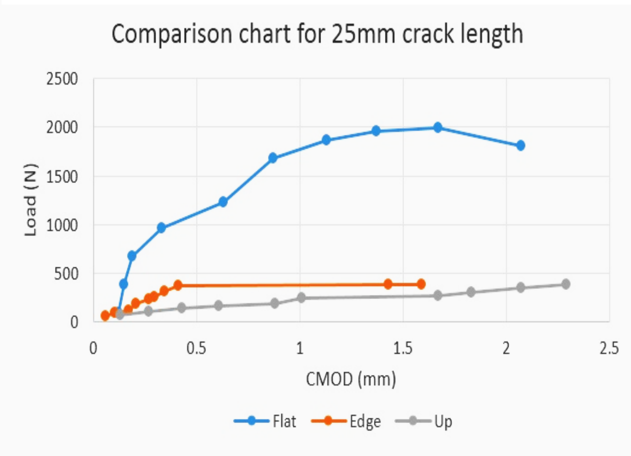
Following are the photographs of ABS specimens after fracture testing:

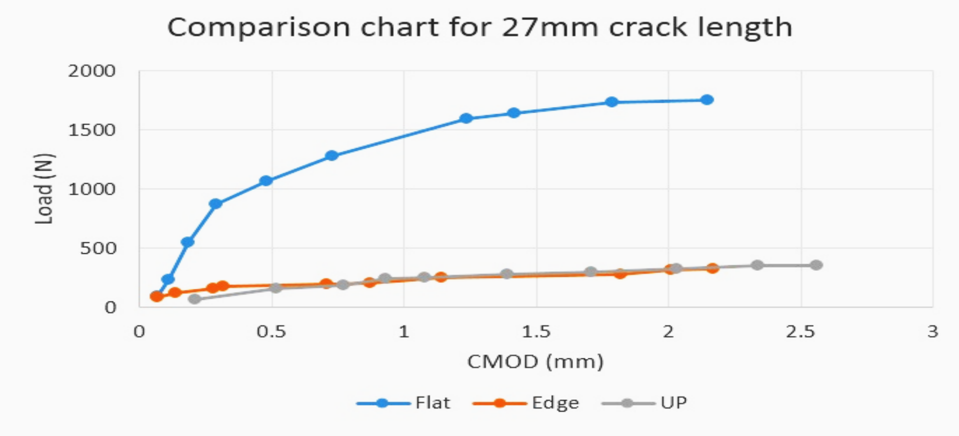
		
(a) Crack length= 23mm Orientation = Flat	(b) Crack length= 25mm Orientation = Flat	(c) Crack length= 27mm Orientation = Flat
		
(d) Crack length= 23mm Orientation =Edge	(e) Crack length= 25mm Orientation =Edge	(f) Crack length= 27mm Orientation =Edge
		
(g) Crack length= 23mm Orientation =Up	(h) Crack length= 25mm Orientation =Up	(i) Crack length= 27mm Orientation =Up

IV. RESULTS

Following are the graphs from the experimental data of Load, CMOD and SIF for 9 specimens.







Following are the result of maximum SIF for 9 specimens.

Orientation	SIF (N√mm)		
	23mm Crack length	25mm Crack length	27mm Crack length
Flat	100.47	108.73	108.2
Edge	19.98	21.15	20.12
Up	20.39	20.82	21.66

V. CONCLUSION

In the present work, an attempt has been made to study the effect of Crack length and layer of orientation of Specimen. From the experimental results, concluded that fracture properties of 3D printed specimens are depends on crack length and Layer orientation. Load require for fracture of specimen are decreases for Flat, Edge and Up specimen. In flat specimen load require for fracture is very high and also the Stress intensity factor is high. For Edge and Up specimens load and SIF value are very close compare to Flat specimens. From Load vs. CMOD graph found that the graph of Flat specimens are differ from Edge and Up specimen. For flat specimens increase in CMOD increase higher load compare to edge and up specimens. Increase in Crack length also increases the value of SIF and decrease the value of load require for facture.

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