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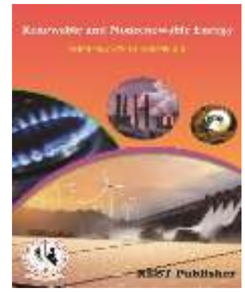

Structural Performance Evaluation of FDM-Printed Abs Composites for Mini UAV Systems

***K Kalyani Radha, B Omprakash**

JNTUACEA, Ananthapuramu, Andhra Pradesh, India.

*Corresponding Author Email: radha.mech@jntua.ac.

Abstract:*The current trend in aircraft structural design is to use composite materials as primary structural elements.The main objective of the project is to design the parts as per ASTM standards by using CATIA V5R21 software and develop Rapid prototyping based composites with adequate structural integrity for subsequent use of Mini Unmanned Air Vehicles. In the present work, an attempt is made on RP technology especially Fused Deposition Modeling (FDM)to make aerodynamic body parts or airframe structures either hollow or porous and its superior properties which in turn would help in weight reduction with enhanced strength, corrosion and fatigue resistant and to build accurately to design specifications.In the present work, ABS (acrylonitrile-butadiene styrene), plastic is electroplated with copper (Cu) and Nickel (Ni) electrolytic solutions. The coating thickness of Cu and Ni layer approximates to 5µm, 35µmand 55µm respectively. These coated samples are subjected to FEM analysis to make a note of increase or decrease in the mechanical strength (Tensile, Flexural, Compression, Impact and Hardness). Analysis is processed on two different types of sample specimens by ANSYS software. The obtained results are compared with the uncoated samples. The result of the simulation indicates that coating bestows an increase in strength to the ABS samples.*

Keywords: *ABS Composite material, FDM technology, FEM, Electroplating, Copper and Nickel.*

1. INTRODUCTION

An Unmanned Air Vehicle (UAV), in simple terms is a flying device/aircraft without a human pilot on board. Its flight is controlled either autonomously by computers in the vehicle or under the remote control of a pilot on the ground or in another vehicle.UAV’s are usually deployed for the military and special operation applications, such as policing and firefighting and non-military security work such as surveillance of pipelines, aerial photography for mapping, survey and disaster control etc., UAV’s are usually preferred for missions that are too dull, dirty or dangerous for manned aircraft.They fly at an altitude of 300m, with a launch weight of 2.5 kg and have an endurance of almost 2 hours. The airframes consist of conventional rib and spar elements manufactured from different lightweight materials like balsa wood, foam, glass fibre and carbon fibre composites.Many groups of researchers are actively involved in development of light weight airframes with adequate strength to sustain loads that are encountered during flight tests. This quest to develop lighter but yet durable and reliable air frames has led to many innovative fabrication approaches. Usage of composites provides an added advantage of stealth.

In such a scenario, this work aims in developing an aero foil for mini UAV’s, with primary importance being given to the crashworthiness (to protect the on board instruments) of the UAV; since MUAV’s don’t have landing gears and crash lands after their flight. The technology of Rapid Prototyping is adopted in fabricating the aero foils. The uses of rapid prototypes in fabricating the aero foils of MUAV’s are limited by their strength, since the rapid prototypes are fabricated from thermoplastics, which usually have low strength. Here the aero foils are fabricated through FDM, which is one of the types of Rapid Prototyping, and their strengths are enhanced through electroplating metal foils over them.

2. LITERATURE REVIEW

*Chandrasekhar,Venkatesh.K, Elangovan.K, Rangaswamy.T [1]*has proposed their paper presenting integrated use of rapid prototyping and metal plating techniques for development of Micro Air Vehicles. FDM and stereo lithography are used to fabricate thermoplastic MAV structure materials, since thermoplastic have low strength, and to make them airworthy, these substrates are coated with layers of metal through electro less and electrolytic deposition process. Experiments are conducted on metal plated thermoplastic test specimens and their mechanical behavior and structural integrity properties are evaluated, there by realizing flight worthy MAV structure.

Mithun VKulkarni, K Elangovan, K Hemachandra Reddy, S a Rodriguez Arthur[2] describesABS (acrylonitrile-butadiene styrene), plastic is electroplated with copper (Cu) and Nickel (Ni) electrolytic solutions. The coating thickness of Cu and Ni layer approximates to 5µm and 35µm respectively. These coated samples are subjected to FEM analysis to make a note of increase or decrease in the mechanical strength (Tensile and Compression). The obtained results are compared with the uncoated samples. The result of the simulation indicates that coating bestows an increase in strength to the ABS samples.

Jamieson[3] described the design of solid models from various resources are converted into STL format files or other format files, which mostly come along with the FDM machines. Slicing procedures are implemented before the deposition. A lot of research is focused on slicing algorithms and attempting to reduce the stair-case effects and anisotropy of the final physical models. Jamieson found that RP systems need for both tessellated and sliced data from CAD models to be input into RP machines and shown that direct slicing can be beneficial in terms of files size and in eliminating the need to slice a tessellated equivalent model. Their work also has shown that the accuracy can be enhanced, especially on rounded or tubular designs, which also benefits from reduced processing time before the build process starts.

3. MODELINGOF FDM SPECIMENS

In this section the modeling of specimens is done according to ASTM standards by CATIA v5 R21 modeling software.
Tensile Specimen (ASTM D638)

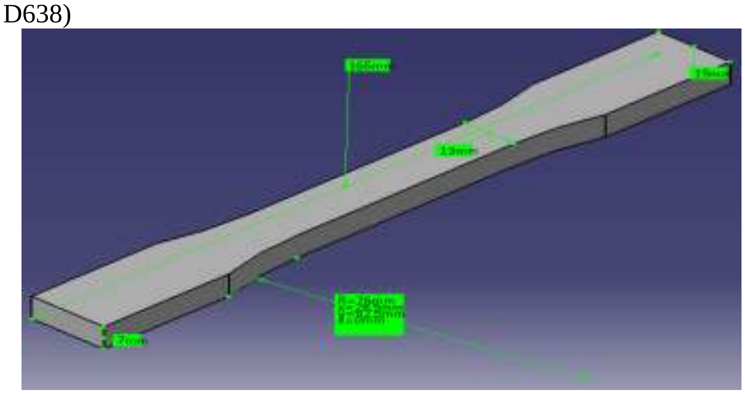

FIGURE 1. Modeling of Tensile Test Specimen

Flexural Specimen (ASTM D790)

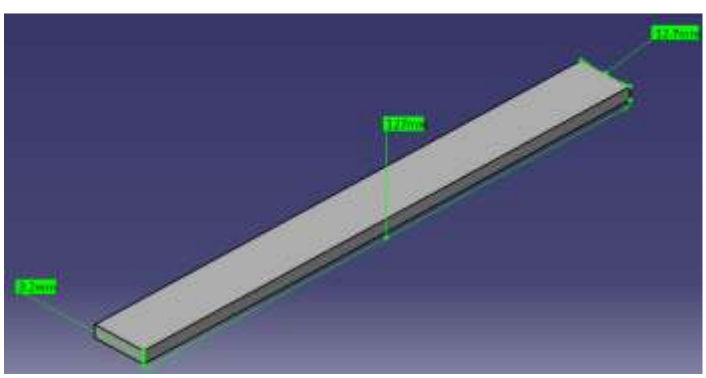

FIGURE 2. Modeling of Flexural Test Specimen

Compression Specimen (ASTM D695)

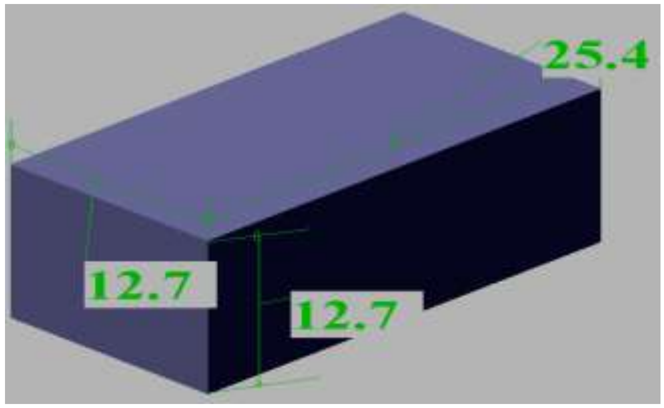

FIGURE 3. Modeling of Compression Test Specimen

Hardness Specimen (ASTM D785)

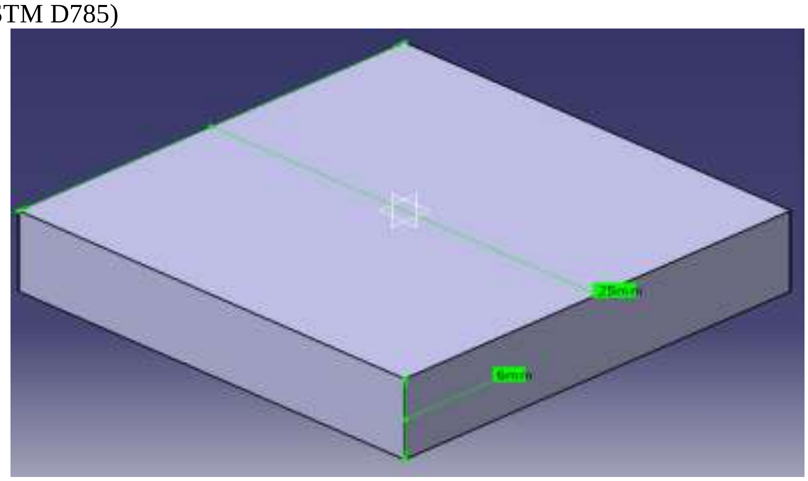

FIGURE 4. Modelling of Hardness Test Specimen

Impact Specimen (ASTM D256)

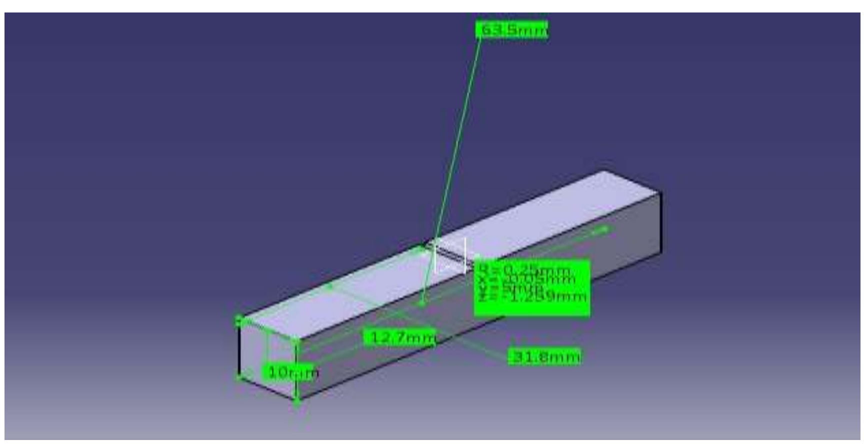

FIGURE 5. Modeling of Impact Test Specimen

TABLE 1. Properties of Abs Composite Materials

Tensile Strength	40-50 Mpa
Notched Impact Strength	10 - 20 Kj/m²
Thermal Coefficient of expansion	70 - 90 x 10^{-6}
Max Cont Use Temp	80 - 95 ^{o}C
Density	1.0 - 1.05 g/cm^3

4. FABRICATION OF FDM SPECIMEN

Fused Deposition Modelling (FDM) deposits extruded thermoplastic filaments for producing the parts. The Tensile, Flexural Compression, Hardness and Impact prototypes are fabricated using Fracktal Julia FDM machine. The specimens are built on a platform which is lowered between layers, to make room for the next layer. Layer thickness is adjusted and controlling of layer thickness is achieved by varying the speed of the extrusion head.

FIGURE 6. Tensile, Flexural, Compression, Hardness and Impact samples used in the study

5. ELECTROPLATING OF ABS PLASTICS

Plating of Plastics (POP) is initially developed using ABS (Acrylonitrile Butadiene Styrene) have been used in more specialist applications where the properties of ABS are too limited. Normally POP of ABS plastics involve the following steps which are etching, activation, electro less plating, acid Cu plating Acid Ni plating and chrome flash. The etching process involves burning of butadiene particles from ABS specimens creating microscopic holes in the same. These microscopic holes act as the site for the deposition of electro palatable materials. The etched specimens are then activated through an activation process in which a catalytic film is deposited on the surface of the etched specimens to prepare the above for electro less metal plating. The activated specimens are then given a thin coat of either nickel or copper using electro lesssolution; this completely prepares the specimen for further electroplating using the conventional route for electroplating metals. The electroplating involves dipping the electro less specimens in acid copper solution and then giving a coat of nickel and finally a coating with Chrome. The electroplated specimens have been indicated in the Fig.7.

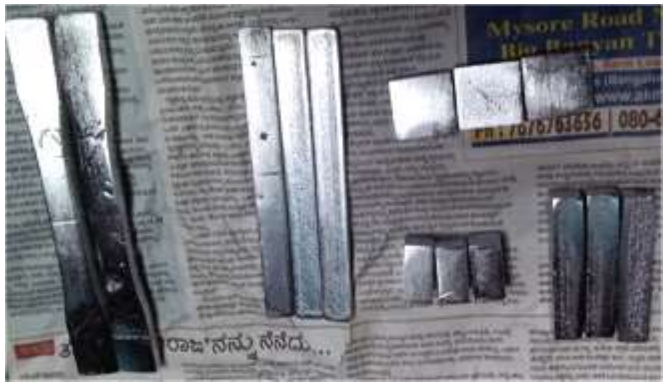

FIGURE 7. Tensile, Flexural, Compression, Hardness and Impact Electroplated samples

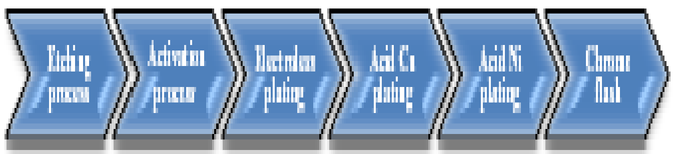

FIGURE 8. Electroplating procedure on ABS plastics

6. ANALYSIS

The simulated model of the Tensile, Flexural, Compression, Hardness and Impact specimens represents the real specimens as tested in the physical experiments. The ANSYS software is a handy tool that has the capability to decide the type of elements that are required for the analysis purpose.

Mesh generation is one of the most critical aspects of engineering simulation. Too many cells may result in long solver runs, and too few may lead to inaccurate results. ANSYS Meshing technology provides a means to balance these requirements and obtain the right mesh for each simulation in the most automated way possible. ANSYS Meshing technology has been built on the strengths of stand-alone, class-leading meshing tools. The strongest aspects of these separate tools have been brought together in a single environment to produce some of the most powerful meshing available. This helps in automatic choosing of elements and nodes and thus simplifies the job of FEM model creation. The meshing is performed by opening the ANSYS meshing application in workbench environment wherein the sizes of the elements are controlled.

A structural model which created can be used to predict the behaviour of their modal structure, under the action of external forces. The response is usually measured in terms of deflection and stress.

TABLE 2. Tensile Test

Condition of Samples	Uncoated	Electroplated		
Layer thickness	--	15 µm	35 µm	55 µm
Mechanical Properties				
Tensile Strength (MPa)	19	21.65	25.6	30.55
% Elongation	1.89	2.2	2.43	2.71
FEA	19.235	21.599	25.467	30.239

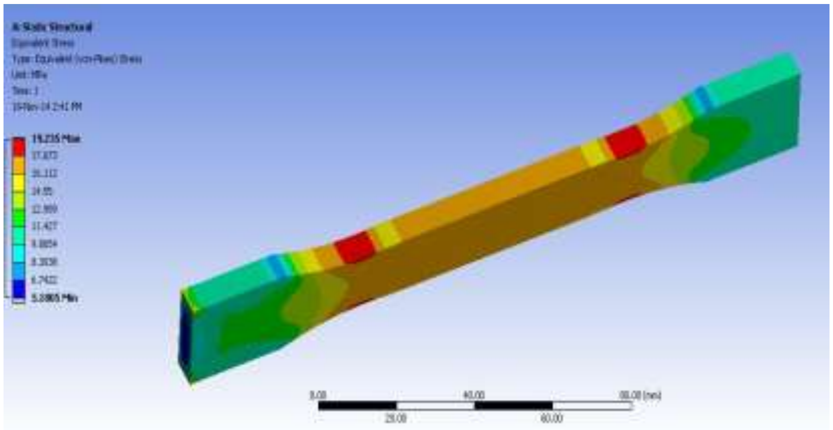

FIGURE 9. Stress Variation for Uncoated Tensile Test Specimen

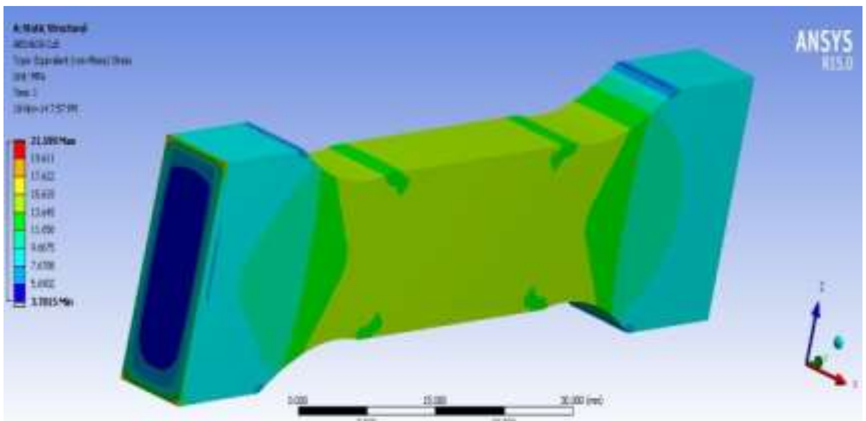

FIGURE 10. Stress Variation for Coated Tensile Test Specimen of 15 µm

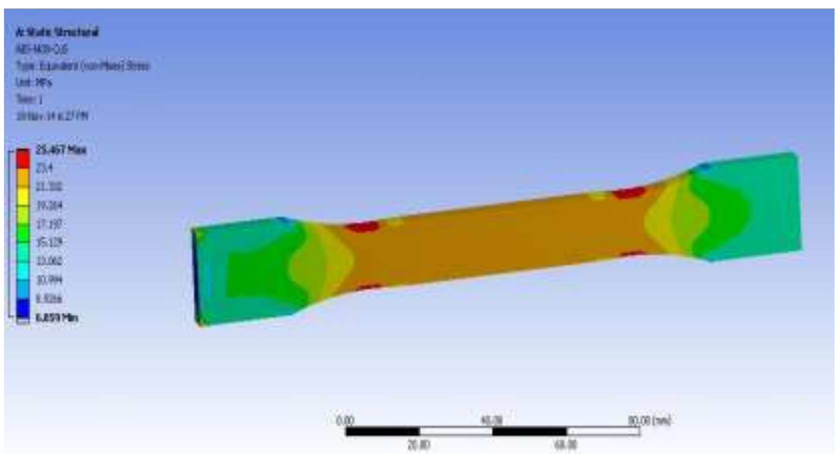

FIGURE 11. Stress Variation for Coated Tensile Test Specimen of35 µm

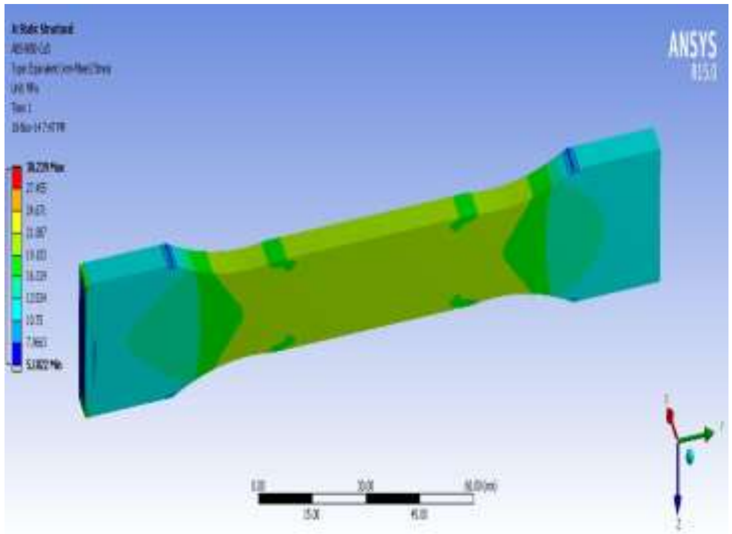

FIGURE 12. Stress Variation for Coated Tensile Test Specimen of55 µm

Tensile Test results:

Flexural Test:

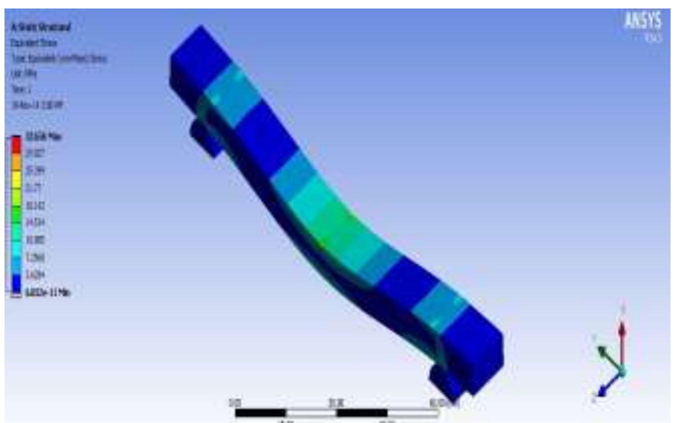

FIGURE 13. Stress Variation for Uncoated Flexural Test Specimen

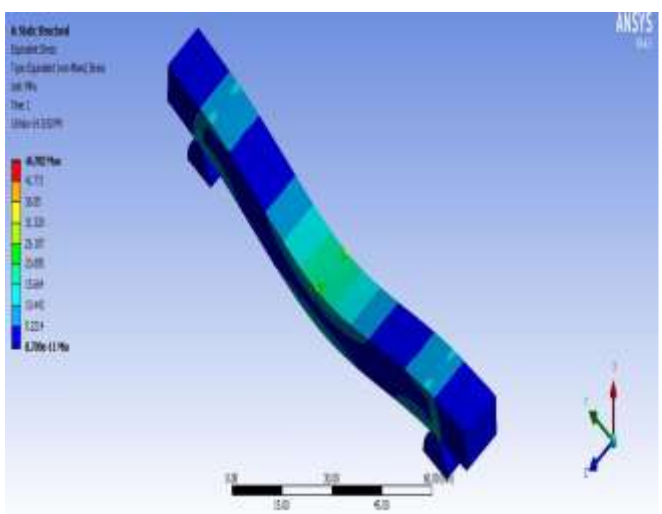

FIGURE 14. Stress Variation for Coated Flexural Test Specimen of 15 µm

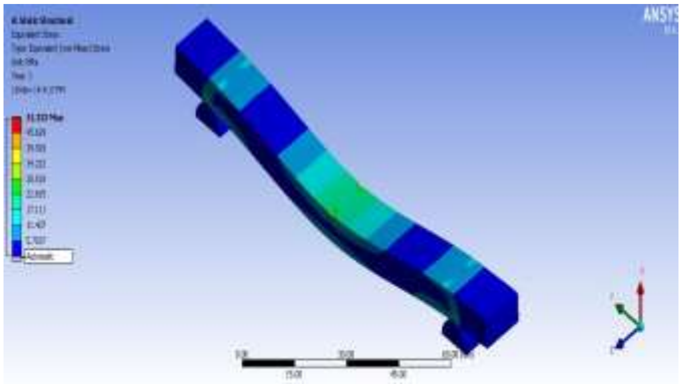

FIGURE 15. Stress Variation for Coated Flexural Test Specimen of 35 µm

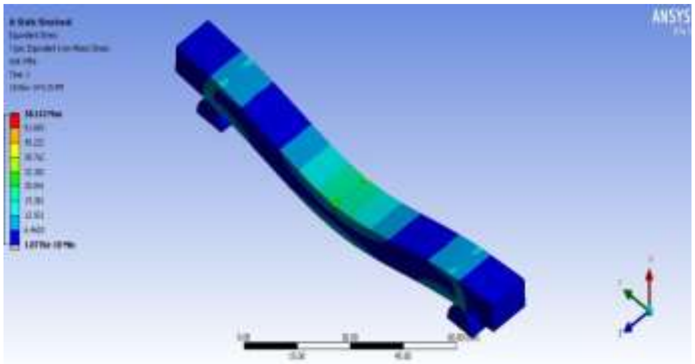

FIGURE 16. Stress Variation for Coated Flexural Test Specimen of 55 µm

TABLE 3. Flexural Test Results

Condition of Samples	Uncoated	Electroplated		
Mechanical Properties	--	15 µm	35 µm	55 µm
Flexural Strength, MPa	32.5	45.466	50.92	57.719
Max deflection, mm	2.65	3.46	3.85	4.46
FEA	32.656	46.992	51.333	58.143

Compression Test:

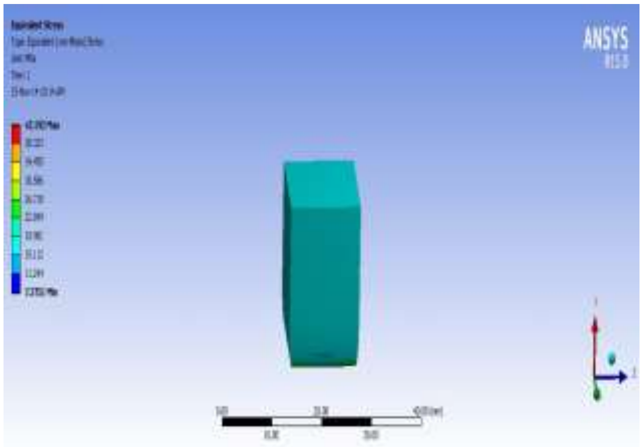

FIGURE 17. Stress Variation for Uncoated Compression Test Specimen

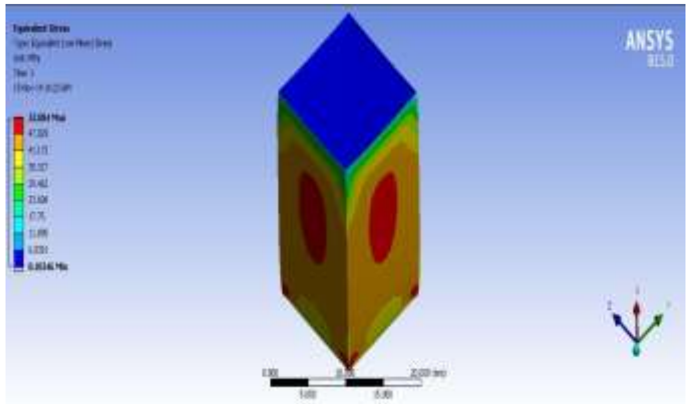

FIGURE 18. Stress Variation for Coated Compression Test Specimen of 15 µm

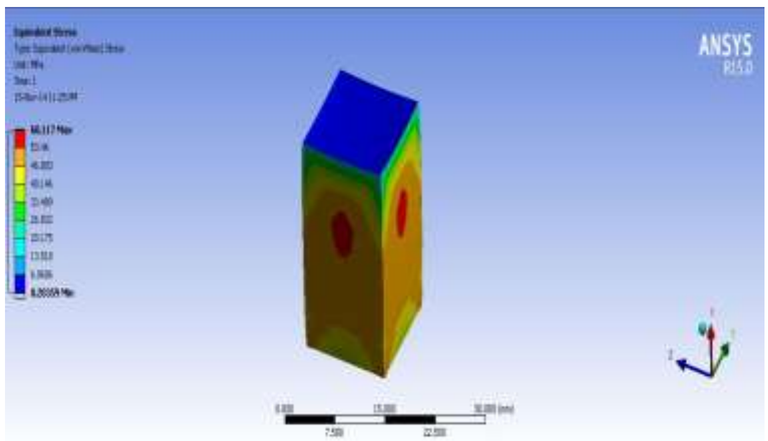

FIGURE 19. Stress Variation for Coated Compression Test Specimen of 35 µm

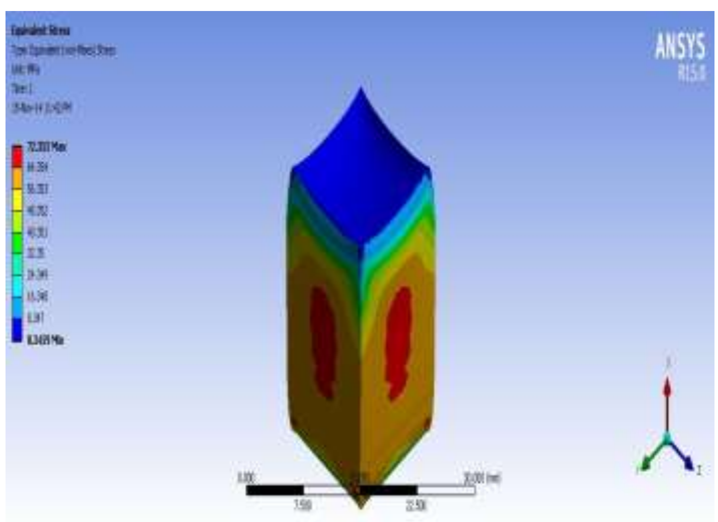

FIGURE 20. Stress Variation for Coated Compression Test Specimen of 55 µm

TABLE 4. Compression Test Results

Sample Type	Compression load (KN)	Compressive Strength, (MPa)		% Variation
		Exp	FEA	
Uncoated	6.680	41.42	42.192	1.86
15 µm	8.588	51.78	52.884	2.132
35 µm	9.829	59.96	60.117	0.2618
55 µm	11.641	72.18	72.355	0.2424

Impact Test:

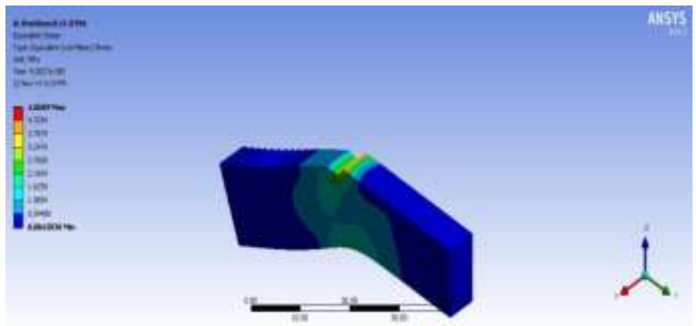

FIGURE 21. Stress Variation for Uncoated Impact Test Specimen

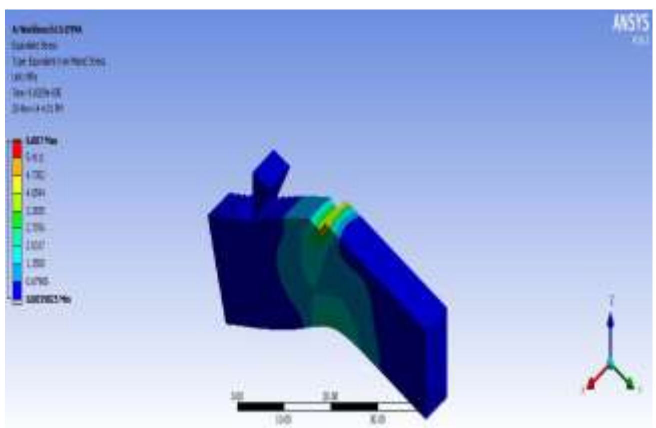

FIGURE 22. Stress Variation for Coated Impact Test Specimen of 15 µm

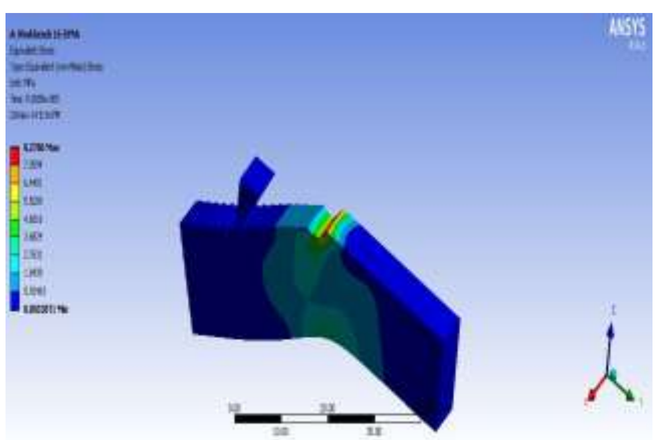

FIGURE 23. Stress Variation for Coated Impact Test Specimen of 35 µm

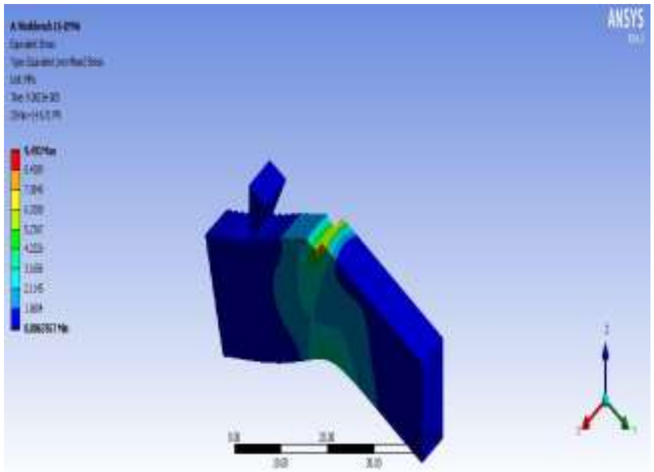

FIGURE 24. Stress Variation for Coated Impact Test Specimen of 55 µm

TABLE 5. Impact Test Results

Sample Type	Fracture Toughness (J)	Impact Strength, (KJ/m^2)	Impact Stress, MPa		% Variation
			Exp	FEA	
Uncoated	0.6228	5.633	4.75	4.868	2.48
15 µm	1.2029	9.351	5.98	6.087	1.78
35 µm	1.6227	12.527	7.96	8.278	3.99
55 µm	1.6169	14.029	9.168	9.493	3.54

7. GRAPHS &DISCUSSIONS

According to results of structural analysis graphs are plotted for the E-glass epoxy and S-glass epoxy composite materials. Graphs are plotted for the Von-misses stress and Deformation.

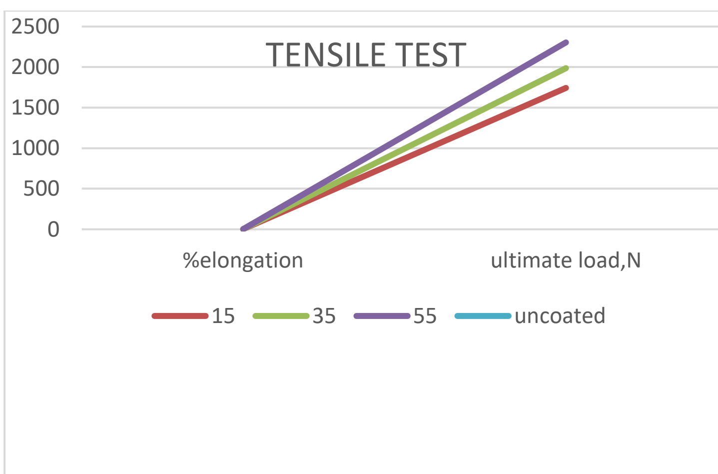

FIGURE 25. Tensile Test results Comparison

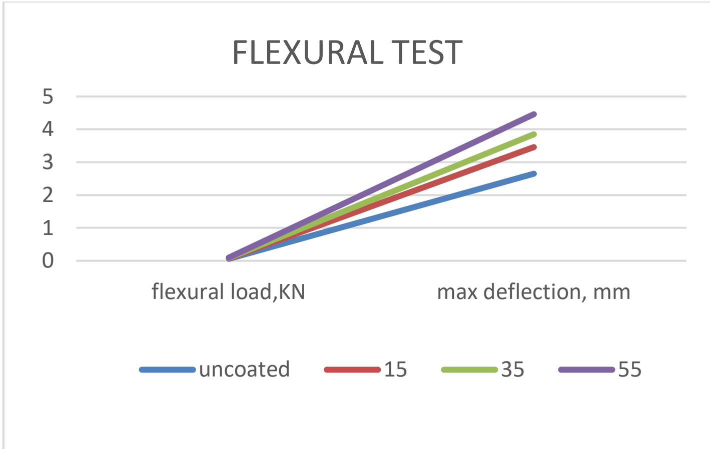

FIGURE 26. Flexural Test results Comparison

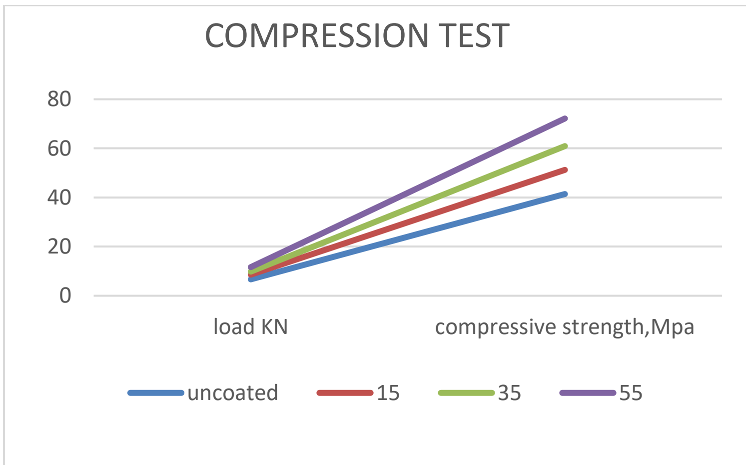

FIGURE 27. Compression Test results Comparison

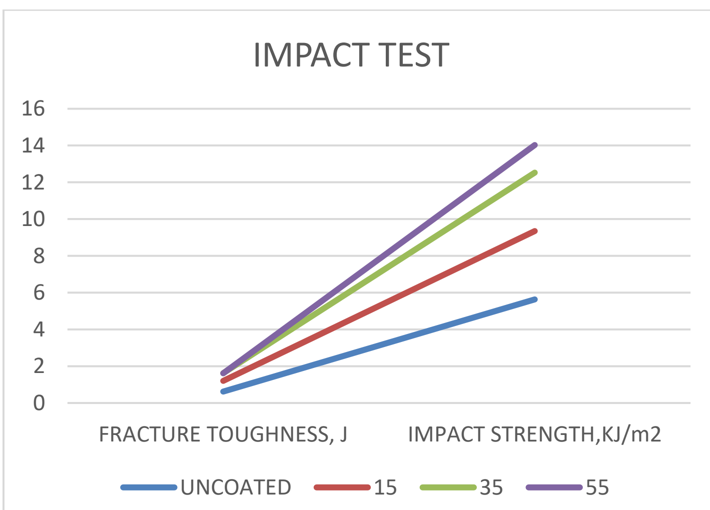

FIGURE 28. Impact Test results Comparison

Tensile test results: The geometrical data input to the computer is taken from the tensile test configuration according to ASTM D 638 standards. The loading and boundary conditions are shown in Figures. The specimen is fixed in the testing machine and the movable jaw is adjusted for the gauge length of 45 mm. The tensile load is gradually applied till the specimen is broken at the average max. Values of 1.74 - 2.81 KN. The load then falls to zero.

The tensile strength obtained for uncoated specimen from this analysis is 19.235 MPa. Its experimental value is observed to be 19 MPa. The variation in the two values is noticed to be 1.23 %. Similarly tensile strength obtained for Coated specimen 15µm, 35 µm and 55 µm from this analysis is 21.599 MPa, 25.467 MPa and 30.239 MPa. Its experimental value is observed to be 21.65 MPa, 25.6 MPa and 30.55 MPa. The variation in the two values is noticed to be 0.236%, 0.522% and 1.028 %.

Flexural test results: The specimen geometry for 3 point bend test as per ASTM D 790 standard. The specimen is held in the testing machine as a simply supported beam and load is gradually applied at the centre. When the applied load reaches ultimate value the specimen breaks and subsequently the load falls to zero.

The computer simulations of flexural test are performed by choosing the ultimate loads recorded in the test. The flexural strength obtained by computer simulation of uncoated flexural test Specimen is 32.656 MPa. It appears to be very close to the experimental value of 32.5 MPa. The variation is 0.48 %. Similarly the flexural strength obtained by computer simulation of coated flexural test Specimen 15µm, 35 µm and 55 µm are 46.992 MPa, 51.333 MPa and 58.143 MPa. It appears to be very close to the experimental value of 46.466 MPa, 50.92 MPa and 57.719 MPa. Thevariations is 1.132%, 0.811% and 0.734%.

Impact test results: The impact process is simulated on the computer by following a transient analysis. The objective of this work is to demonstrate the explicit dynamics using ANSYS LS-DYNA for complex contact dynamics situation which simulates Izod impact test of experimentation. During the free fall stage, the striker is simply accelerating due to gravity. The analysis is started when the striker is 0.5 m above the specimen in order to save CPU time. The initial velocity of 3 ms-1 is applied to simulate the process. This velocity is an approximation obtained by using V= (2gh) 1/2 where g is acceleration due to gravity and h is displacement. Air friction is assumed to be neglected.

The striker is constrained to have translations in y-direction (1dof). It is restrained to have translations in x, z directions and rotations about x, y, z directions. The Impact Stress obtained from ANSYS for Uncoated Impact Test Specimen is 4.868 MPa, whereas the actual experimental value for the specimen is 4.75 MPa. The percentage variation is 2.48%. Similarly the Impact Stress obtained from ANSYS for Coated Impact Test Specimens 15µm, 35 µm and 55 µm are 6.087 MPa, 8.278 MPa and 9.493 MPa, whereas the actual experimental value for the specimens are 5.98 MPa, 7.96 MPa and 9.168 MPa. The percentage variation is 1.78, 3.99 and 3.54%.

Compression Test results: 3D solid model of compression sample stored in IGES format was imported into the ANSYS workbench. The model was generated as per the ASTM D695 standard. Required layers (copper and nickel) were created on the base ABS sample in the modelling stage itself. The material property for the layers was fed into the engineering data toolbox of ANSYS workbench. The analysis shown in this section is of 15µm, 35µm and 55µm coated compression samples.

The analysis is completed when the load reached a maximum value of 6.6KN – 13.65KN for all the samples (uncoated and coated) under consideration. The maximum compressive stress observed in case of uncoated and 15µm, 35 µm and 55 µm samples were 42.192MPa, 52.884 MPa, 60.117MPa and 72.355MPa. The experimental results were 41.42MPa, 51.78MPa, 59.96MPa and 72.18MPa. A variation of 1.86%, 2.132%, 0.2618% and 0.2424% was observed for uncoated and 15µm, 35µm and 55µm sample.

Hardness Test results: The Rockwell method for ASTM D785 for uncoated and 15µm, 35µm and 55µm coated samples measures the permanent depth of indentation produced by a force/load on an indenter. First, a preliminary test force (commonly referred to as preload or minor load) is applied to a sample using a diamond indenter. This load represents the zero or reference position that breaks through the surface to reduce the effects of surface finish. After the preload, an additional load, call the major load, is applied to reach the total required test load. This force is held for a predetermined amount of time (dwell time) to allow for elastic recovery. This major load is then released and the final position is measured against the position derived from the preload, the indentation depth variance between the preload value and major load value. This distance is converted to a hardness number. Preliminary test loads (preloads) range from 3 kgf (used in the “Superficial” Rockwell scale) to 10 kgf (used in the “Regular” Rockwell scale) to 200 kgs (used as a macro scale and not part of ASTM E-18; see ASTM E-1842). Total test forces range from 15kgf to 150 kgf (superficial and regular) to 500 to 3000 kgf (macro hardness).The hardness number is observed in case of uncoated and 15µm, 35µm and 55µm coated samples were HRR 40.7, 62.2, 63.6 and 64.5 respectively.

8. CONCLUSION

FEM analysis was conducted based on the experimental data obtained from the tests and the results obtained from the experimental study were given as an input to create the database of the materials under study. the values of the effective tests carried out for Cu-Ni coated and non coated ABS composite models from Finite Element Method (FEM)which are in reasonable agreement with the experimental values for a wide range of filler content and was found that more thickness of coating on ABS specimens results in improvement of Strength and Stiffness of composites.The results of the analysis concluded that the values obtained were very much closer to the experimental results thereby can be used for UAV related applications.

Scope of Future Work: The present work can be extended for FDM technique for fabricating UAV parts using ABS materials is a quick, easy, cost effective fabrication that is considered and could have a promising future in the construction of UAV. From this project, it is evident that electroplating can be used to enhance the characteristics when used with ABS materials. Hence it has a huge potential to be used for UAV and Space related applications.

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