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Experimental Investigation and Design Analysis of Hollow Glass Microsphere loaded PP/ABS Composites

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Abstract: The objective of the present is to investigate hollow glass microspheres (HGMs) experimentally and carry out design analysis of hollow glass microsphere loaded PP/ABS composites. The tensile and notched Charpy impact test of HGM-filled acrylonitrile-butadiene-styrene copolymer (ABS) and Polypropylene (PP) composites will be studied with varying the concentrations of PP/ABS composite with HGM. Also further the design analysis will be studied by conducting the simulation under the same criteria and comparing the results at the end. This is done to introduce a light weight material without compromising specific strength of PP/ABS composite by adding HGM to the composite.
Keywords: Hollow Glass Microsphere (HGM), ABS-Acrylonitrile butadiene styrene, PP- Polypropylene, Composites.

I. INTRODUCTION

With the increase in industrial demands it is very essential to build materials that are strong but have less weight.Vivek et al. [13] investigated the effect of nano-sized alumina particles in ABS thermoplastic composites in which ABS was reinforced with nano-sized alumina particles via melt compounding.SEM micrographs revealed a higher dispersion rate, and ABS demonstrated a 10% increase in weight loss at a specific temperature. At 3vol% alumina content, the flexural modulus increases by about 23%.Budrun et al. [4] experimentally examined the mechanical and physical behaviors of the ABS reinforced with palm fiber.

Dunne et al. [11] pragmatically carried out the Mechanical testing of natural fibre composites using an acrylonitrile butadiene styrene matrix (ABS). The poroelastic natural fibre composites had tensile strengths ranging from 171 to 599 kPa. The airflow resistivity of 100 percent kenaf was found to be the highest. The 50% kenaf composite had the lowest airflow resistivity and tensile strength, but also the lowest density, which is a good thing. The densities of the poroelastic natural fibre composites still need to be optimized. S.M.D Mastan et al. [12] empirically determined that in the presence of a compatibilizer, hybrid PP/ABS reinforced fillers were successfully prepared using a twin-screw extruder followed by injection moulding. The addition of hybrid fillers increases the percent crystallinity of the PP phase in a PP/ABS blend, as does the thermal stability of the PP/ABS blend.

Kareem et al. [7] kept the figures in which the matrix is made of polypropylene, and the filler is made of waste tyre particles and the PP had a density of 960 kg/m3 and a flow index of 1.35 gm/min.The coefficient of thermal expansion for rubber particles polypropylene composite is 0.00022 mm/ mmC on average across the entire temperature range, which is 20% lower than the CTE of PP. As a result, the CTE of rubber particles polypropylene composite is lower than that of PP polymer, resulting in rubber particles polypropylene composite having better dimensional stability than PP polymer. Ganesh et al. [5] mixed ABS as a rubber phase copolymer and carbon black (CB) as a filler material.Tensile strength and Tensile Modulus Were Increased By Adding a 2.5 Wt% Of Cb Filled 80/20(Wt/Wt) Pp/Abs Blends, And Impact Strength Was increased by adding 5 wt% of CB filled 80/20(wt/wt) PP/ABS blends.

Bruno et al. [3] mentioned about the pellets that were made by combining chopped carbon fibre in two lengths (3 mm and 6 mm) with ABS GP-35 at two different weight percentages (5 percent wt and 16.7 percent wt). At temperatures above 200°C, the ABS polymer displayed signs of degradation in the FTIR spectra.Aiah Mohamed et al. [2] investigated the mechanical, melt-flow, and morphological actions of perlite reinforced ABS composites.Tensile strength of ABS/PER composites improved with 2.5 percent and 5 percent PER inclusions.Further additions resulted in a decrease in tensile strength values which was further examined by SEM on identifying presence of weak interfacial interactions.

The aims of the study are:

- To fabricate hollow glass microsphere loaded PP/ABS composites with different weight% of HGM.
- Carry out Experimental Investigation to test the strength of the various samples.

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II. EXPERIMENTAL WORK

A. Materials Required

Polypropylene is chosen as matrix due to its huge usage in market and easiness in making a composite. The benefits of polypropylene (PP) include high heat alteration in temperature, better processibility, and low cost. Its only drawback is that it has lower impact properties. It is combined with Acrylobutadiene Styrene for this purpose (ABS). Among the various polymers, PP is a critical plastic commodity that is widely used to manufacture products by a variety of industries..They are also used in buildings and switch boards for their insulation property. Hollow glass microsphere is chosen as the particle reinforcement for its low density and high compressive strength. Polypropylene is selected due to its immense applications in commercial market and it can be easily moulded into a composite. Polypropylene (Injection Grade-H110MA) was procured from Guntur after thorough search in Chennai and Bangalore. The composite is to be manufactured with PP/ABS as matrix and hollow glass microsphere as the particle reinforcement. The weight percentage of hollow glass microsphere in the PP/ABS matrix is varied to enhance both mechanical and thermal properties of the matrix. Samples with varying weight percentage of hollow glass microspheres are extruded and further moulded for tension and impact tests using injection moulding machine. Mould for compression test sample is not available.

B. Mixing of Particles with Matrix

Polypropylene/Acrylobutadiene Styrene matrix is mixed with hollow glass microsphere. Five samples are prepared having the following weight percentage of HGM - 0, 5, 10, 15 and 20. The remaining weight percentage in the sample consists of polypropylene. Each sample has a total weight of 100 grams. Weight of the sample constituents is carefully measured by the weight balance and is stored in beakers for further processing. Beakers are covered with aluminium foil. The five beakers are dried in an oven in vacuum environment for one hour to remove any moisture present in the sample at a temperature of 40 degree Celsius.

C. Preparation of Composite

Four plastic bags containing the matrix of weight 150 grams is used in the twin screw extruder to clean any sample left over from the previous operation. Temperature in the three chambers of the twin screw extruder are 120, 220, 250 degree Celsius to ensure that the sample can be extruded without degradation. The samples are fed into the twin screw extruder in conical flask with help of spatula. While the mixture travels through the heating chambers of extruder, mixture gets heated and gets melted. This melted mixture is received at the other end of extruder through a small circular cross section hole in the form of continuous wire. Feeding of mixture in the flask should be slow enough especially with samples with higher composition of hollow glass microspheres as it being in the nature of powder tends to get carried away in the air. Extruded material obtained from the extruder is pulled at the correct speed to ensure the correct thickness. Too high speed results in a thin cylindrical mixture whereas during a slow speed the sample tends to wound near the extrusion hole. The extruded material coming out initially from the hole is ignored as it may contain constituents of the previous sample which was extruded. Collected extruded material is further chopped into small pieces for ease of storing, carrying and injection purpose.

D. Injection Moulding

Tensile and Impact samples are prepared by injection moulding process.The chopped pieces are fed into the injection moulding machine through a conical flask to make two UTM moulds and two Impact moulds for each sample. The temperature is set at 235 degree Celsius in the machine for the sample to be forced into the mould. The mould is kept in the injection moulding machine for three minutes so it is at a higher temperature which reduced thermal cracking and allows more uniform heating.After injection, the mould is opened and the Tension / Impact mould is extracted by a hammer and nail. Impact sample was also prepared by the same procedure with the mould being changed to get the desired shape for the impact sample.

E. Tensile Test

The tensile strength of the PP/ABS and hollow glass microspheres composite specimen is tested using a Universal Tensile Testing machine. The test specimen was prepared in accordance with ASTM standards D3037/3039. Injection moulding was used to create two dumbbell-shaped samples of each set of PP/ABS composites with different compositions of hollow glass microspheres. The width and thickness of dumbbell bridge samples were measured using a digital Vernier Calliper.The test was performed at a pulling rate of 3mm/min. After the sample was measured, the software recorded the tensile strength, modulus, and elongation at break. SEM was used to examine the tensile fracture surface in order to determine the nature of the fracture.

F. Impact Test

The impact strength of the PP/ABS and hollow glass microspheres composite specimen was tested using an impact testing machine. The apparatus is made up of a known mass and length pendulum that is dropped from a known height to strike a notched specimen of material. The amount of energy transferred to the material can be calculated by comparing the height of the hammer before and after the fracture (energy absorbed by the fracture event).

G. Scanning Electron Microscopy(SEM)

SEM is an important characterization tool to directly imaging micro particles in order to obtain quantitative measures of particle, grain size, and morphology.The fractured surfaces of the HGM reinforced with PP/ABS composite were SEM-ed to investigate the HGM-PP/ABS interaction and the microstructural changes that occur when HGM is incorporated into the PP/ABS matrix.

III.RESULTS AND DISCUSSIONS

A. Density

TABLE I
EXPERIMENTAL DENSITY OF EACH SAMPLE

Sample Designation	Sample Name	Density(g/cm^{3})
PA	80% PP+ 20% ABS	0.958
PAH5	95% PP/ABS+ 5% HGM	0.781
PAH10	90% PP/ABS+ 10% HGM	0.623
PAH15	85% PP/ABS+ 15% HGM	0.537
PAH20	80% PP/ABS+ 20% HGM	0.518

Density of PP: 0.91 g/cc; Density of ABS: 1.16 g/cc; Density of HGM: 0.15 g/cc

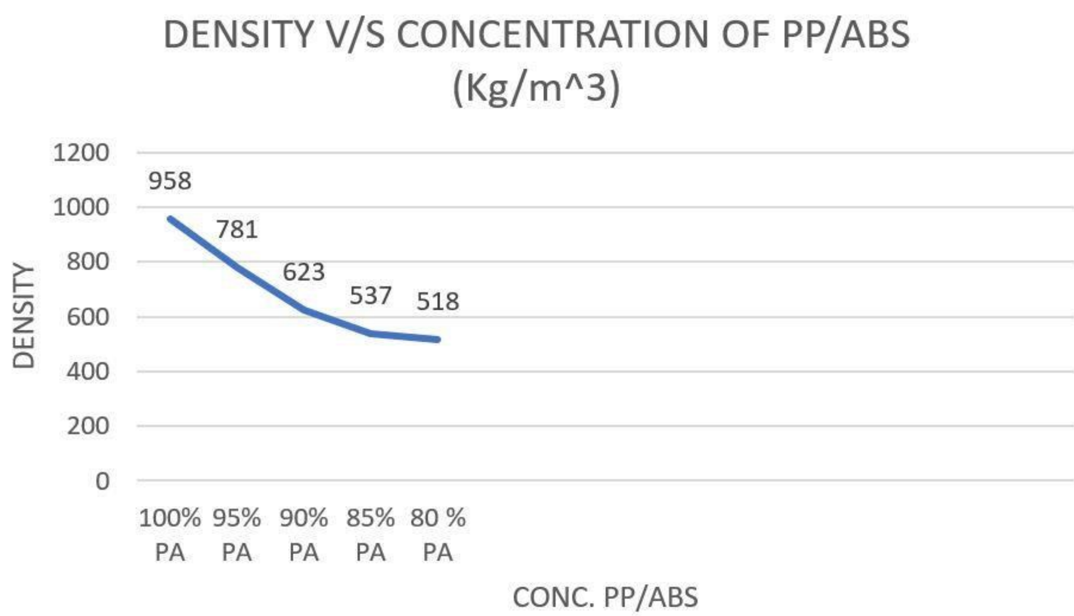

Fig. 1 Density of Each Sample

Results from Table I and Fig. 1 show the decrease in density as the percentage of HGM increases in the composite of PP/ABS with minimum of 0.518 at 20% . Structure of hollow glass microspheres is hollow by nature. Thus, sample having higher weight percentage of hollow glass microspheres will have lower density than those with lower percentage.

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B. Tensile Strength

TABLE III
TENSILE STRENGTH OF EACH SAMPLE

Sample Designation	Maximum Load(N)	UTS(MPa)	Modulus(GPa)
PA	270.33091	34	0.57409
PAH5	200.92726	25	0.643923
PAH10	134.31311	17	0.589527
PAH15	113.99984	15.12	0.74301
PAH20	96.21382	12	0.793155

Results from Table 3.2 show that the composite has a maximum value of Ultimate Tensile strength of 34 when hollow glass microsphere are absent. The composite has a maximum value of Young's Modulus of 0.793155 when weight percentage of hollow glass microspheres is 20% in the composite.

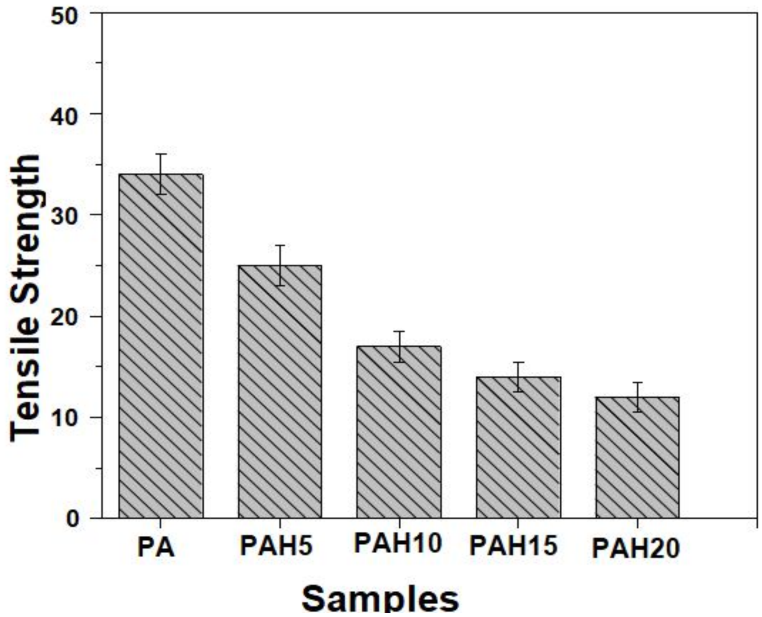
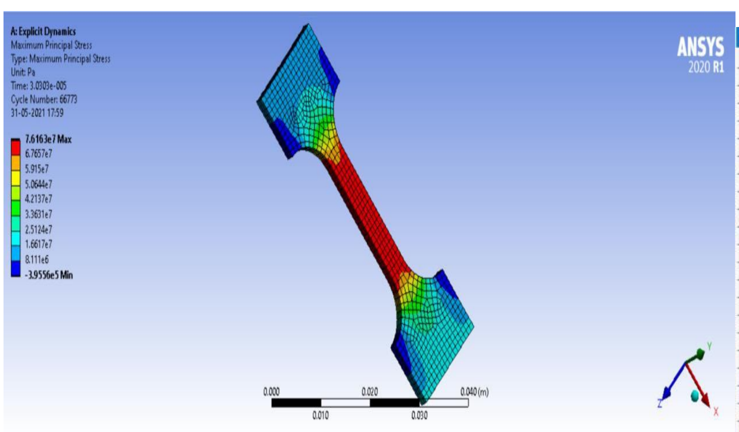
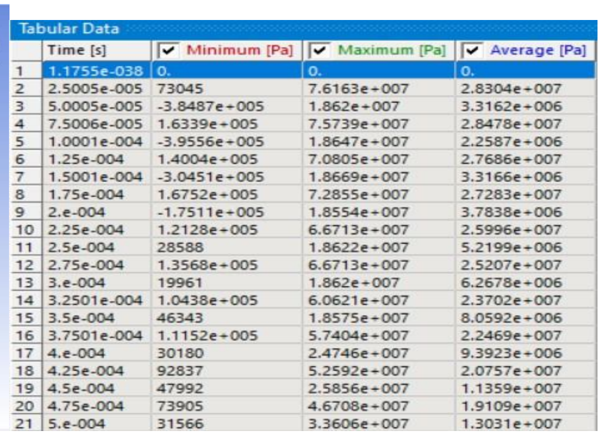


Fig. 2 Tensile strength of PP/ABS based composites with the variation of HGM

C. Ansys Simulation





Tabular Data

	Time [s]	Minimum [Pa]	Maximum [Pa]	Average [Pa]
1	1.1755e-038	0.	0.	0.
2	2.5005e-005	73045	7.6163e+007	2.8304e+007
3	5.0005e-005	-3.8487e+005	1.862e+007	3.3162e+006
4	7.5006e-005	1.6339e+005	7.5739e+007	2.8478e+007
5	1.0001e-004	-3.9556e+005	1.8647e+007	2.2587e+006
6	1.25e-004	1.4004e+005	7.0805e+007	2.7686e+007
7	1.5001e-004	-3.0451e+005	1.8669e+007	3.3166e+006
8	1.75e-004	1.6752e+005	7.2855e+007	2.7283e+007
9	2.e-004	-1.7511e+005	1.8554e+007	3.7838e+006
10	2.25e-004	1.2128e+005	6.6713e+007	2.5996e+007
11	2.5e-004	28588	1.8622e+007	5.2199e+006
12	2.75e-004	1.3568e+005	6.6713e+007	2.5207e+007
13	3.e-004	19961	1.862e+007	6.2678e+006
14	3.2501e-004	1.0438e+005	6.0621e+007	2.3702e+007
15	3.5e-004	46343	1.8575e+007	8.0592e+006
16	3.7501e-004	1.1152e+005	5.7404e+007	2.2469e+007
17	4.e-004	30180	2.4746e+007	9.3923e+006
18	4.25e-004	92837	5.2592e+007	2.0757e+007
19	4.5e-004	47992	2.5856e+007	1.1359e+007
20	4.75e-004	73905	4.6708e+007	1.9109e+007
21	5.e-004	31566	3.3606e+007	1.3031e+007

Fig. 3 (a)Ansys Simulation for pure PP/ABS Composite and (b)Results for Ansys simulation (PP/ABS).

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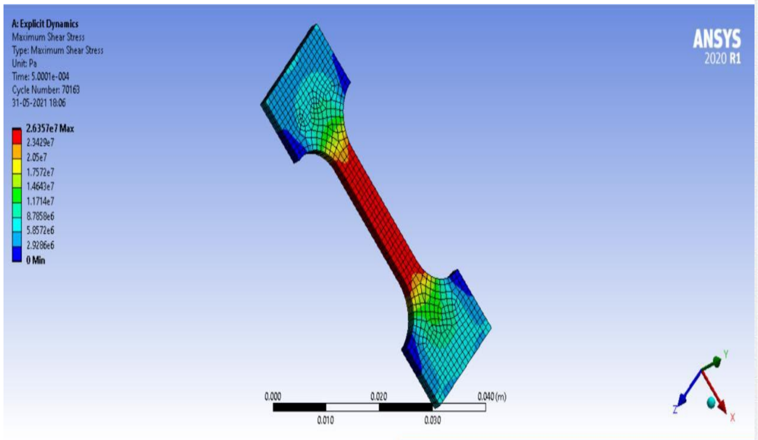
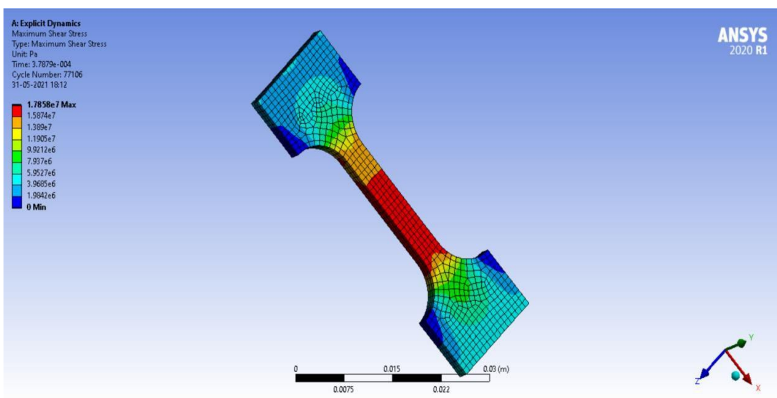


Tabular Data

	Time [s]	Minimum [Pa]	Maximum [Pa]	Average [Pa]
1	1.1755e-038	0.	0.	0.
2	2.5007e-005	6572.2	7.8006e+006	1.1652e+006
3	5.0005e-005	22077	7.6933e+006	1.7184e+006
4	7.5003e-005	36721	7.5698e+006	1.4603e+006
5	1.e-004	4473.4	7.604e+006	1.6933e+006
6	1.25e-004	33721	7.678e+006	2.2611e+006
7	1.5e-004	24983	7.706e+006	2.6966e+006
8	1.75e-004	26828	8.6117e+006	3.3555e+006
9	2.0001e-004	22679	9.2902e+006	4.1508e+006
10	2.2501e-004	21622	1.1183e+007	4.8654e+006
11	2.5001e-004	26289	1.2695e+007	5.5354e+006
12	2.75e-004	28876	1.5334e+007	6.3703e+006
13	3.e-004	33996	1.6464e+007	7.1044e+006
14	3.25e-004	40378	1.913e+007	7.7591e+006
15	3.5001e-004	44048	2.0754e+007	8.433e+006
16	3.75e-004	46522	2.1762e+007	9.0299e+006
17	4.e-004	50137	2.3185e+007	9.4939e+006
18	4.25e-004	54227	2.4855e+007	9.9469e+006
19	4.5e-004	58830	2.5941e+007	1.0301e+007
20	4.75e-004	58235	2.6263e+007	1.0505e+007
21	5.0001e-004	58043	2.6357e+007	1.0624e+007

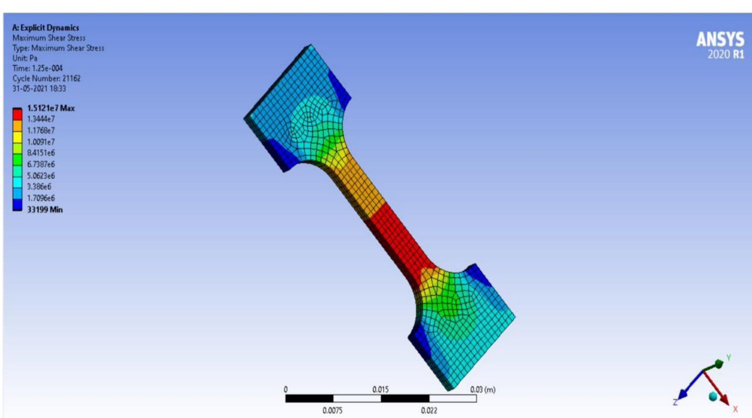
Fig. 4 (a)Ansys Simulation for 5% HGM in PP/ABS Composite and (b)Results for Ansys simulation (PP/ABS) with 5% HGM.



Tabular Data

	Time [s]	Minimum [Pa]	Maximum [Pa]	Average [Pa]
1	1.1755e-038	0.	0.	0.
2	2.5004e-005	54024	1.7536e+007	7.1522e+006
3	5.0004e-005	6692.1	5.205e+006	1.521e+006
4	7.5001e-005	44285	1.1944e+007	5.0872e+006
5	1.e-004	20809	9.9627e+006	4.1852e+006
6	1.25e-004	9299.3	5.4108e+006	2.3206e+006
7	1.5e-004	31111	1.607e+007	6.5596e+006
8	1.75e-004	1475.2	5.1456e+006	9.6011e+005
9	2.e-004	35164	1.7565e+007	7.18e+006
10	2.25e-004	13257	5.1659e+006	1.1632e+006
11	2.5e-004	26566	1.3532e+007	5.7294e+006
12	2.75e-004	16672	8.0587e+006	3.3744e+006
13	3.0001e-004	12551	7.3594e+006	3.1285e+006
14	3.25e-004	28291	1.442e+007	5.9152e+006
15	3.5e-004	6849.3	5.1401e+006	1.0454e+006
16	3.75e-004	34573	1.7858e+007	7.0717e+006
17	4.e-004	57839	5.239e+006	1.4216e+006
18	4.25e-004	73259	1.2622e+007	4.4314e+006
19	4.5e-004	1.0379e+005	1.5628e+007	6.0975e+006
20	4.75e-004	15965	5.1264e+006	8.8201e+005
21	5.e-004	27128	1.7298e+007	6.7432e+006

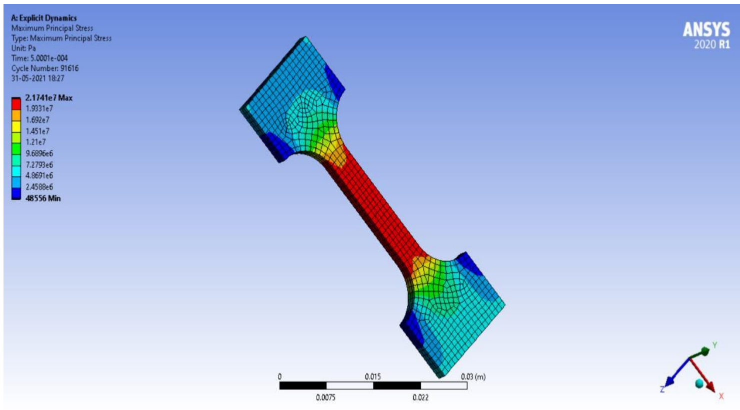
Fig. 5 (a)Ansys Simulation for 10% HGM in PP/ABS Composite and (b)Results for Ansys simulation (PP/ABS) with 10% HGM.



Tabular Data

	Time [s]	Minimum [Pa]	Maximum [Pa]	Average [Pa]
1	1.1755e-038	0.	0.	0.
2	2.5003e-005	24392	4.5561e+006	9.0809e+005
3	5.e-005	18797	4.5518e+006	1.9975e+006
4	7.5002e-005	20715	8.611e+006	3.5559e+006
5	1.e-004	29660	1.2458e+007	5.0026e+006
6	1.25e-004	33199	1.5121e+007	5.8794e+006
7	1.5e-004	36845	1.5409e+007	6.1157e+006
8	1.75e-004	28452	1.3842e+007	5.4606e+006
9	2.e-004	21304	1.0311e+007	4.2607e+006
10	2.25e-004	11855	6.1885e+006	2.7544e+006
11	2.5e-004	4655.4	4.3934e+006	1.4233e+006
12	2.75e-004	1236.6	4.3801e+006	6.6281e+005
13	3.e-004	1281.7	4.3736e+006	6.7414e+005
14	3.25e-004	5360.4	4.3843e+006	1.4834e+006
15	3.5001e-004	12179	6.1662e+006	2.7826e+006
16	3.75e-004	18833	1.0164e+007	4.2266e+006
17	4.e-004	23618	1.3347e+007	5.3046e+006
18	4.25e-004	65146	1.2776e+007	4.8432e+006
19	4.5e-004	47177	5.7448e+006	2.2164e+006
20	4.75e-004	25999	5.1566e+006	2.1328e+006
21	5.e-004	11933	7.9999e+006	3.4178e+006

Fig. 6 (a)Ansys Simulation for 15% HGM in PP/ABS Composite and (b)Results for Ansys simulation (PP/ABS) with 15% HGM.



Tabular Data

	Time [s]	Minimum [Pa]	Maximum [Pa]	Average [Pa]
1	1.1755e-038	0.	0.	0.
2	2.5005e-005	53118	2.2493e+007	8.5483e+006
3	5.0003e-005	31014	1.4165e+007	5.7401e+006
4	7.5003e-005	-29955	6.7538e+006	1.7362e+006
5	1.e-004	55370	2.5342e+007	9.7741e+006
6	1.25e-004	10758	6.6797e+006	2.7066e+006
7	1.5001e-004	27349	1.0314e+007	4.4957e+006
8	1.75e-004	56385	2.3983e+007	9.1492e+006
9	2.e-004	-29865	6.6354e+006	1.0548e+006
10	2.25e-004	37744	1.8359e+007	7.3608e+006
11	2.5e-004	34803	1.6571e+007	6.783e+006
12	2.7501e-004	1597.1	6.6701e+006	1.364e+006
13	3.e-004	53900	2.4024e+007	9.2525e+006
14	3.25e-004	19349	9.0064e+006	3.9032e+006
15	3.5e-004	14546	7.9518e+006	3.4276e+006
16	3.75e-004	54738	2.4196e+007	9.3304e+006
17	4.e-004	3690.3	6.6652e+006	1.7599e+006
18	4.2501e-004	31601	1.51e+007	6.2169e+006
19	4.5e-004	42761	1.9306e+007	7.6511e+006
20	4.75e-004	1525.	6.6474e+006	1.3178e+006
21	5.0001e-004	48556	2.1741e+007	8.4667e+006

Fig. 7 (a)Ansys Simulation for 20% HGM in PP/ABS Composite and (b)Results for Ansys simulation (PP/ABS) with 20% HGM.

TABLE IIIII

RESULTS OF ANSYS SIMULATION COMPILED WITH EXPERIMENTAL RESULTS

Sample	Maximum Load(N)	Modulus(GPa)	UTS(MPa)	ANSYS UTS
PA	270.33091	0.57409	34	33.6
PAH5	200.92726	0.643923	25	26.36
PAH10	134.31311	0.589527	17	17.2
PAH15	113.9984	0.74301	15.12	16.03
PAH20	94.21382	0.79315	12	11.36

The results of experimentation and simulation for tensile stress match each other with minor error as shown in Table III.

D. Impact Energy

TABLE IVV

RESULTS OF ANSYS SIMULATION COMPILED WITH EXPERIMENTAL RESULTS

Sample	**Impact Energy(kJ/m)**
PA	0.321
PAH5	0.394
PAH10	0.461
PAH15	0.512
PAH20	0.423

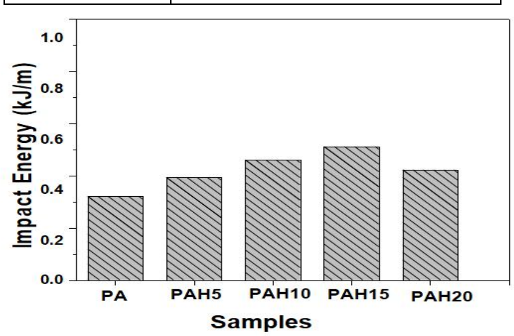


Fig. 8 Impact energy of PP/ABS based composites with the variation of HGM.

Results from Table IV and Fig. 8, show there is an increase in Impact Energy among the samples up to a concentration of 15% of HGM by weight in the composite, but decreases on further increase in concentration of HGM.

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TABLE V
EFFECT ON TENSILE AND IMPACT STRENGTH OF PP/ABS COMPOSITE

Composite Concentration(PP/ABS)	Percentage Decrease in Tensile Strength	Percentage Increase in Impact Strength
With 5% HGM	26.47%	22.74%
With 10% HGM	50%	43.6%
With 15% HGM	58.8%	59.5%
With 20% HGM	64.7%	31.77%

It is advisable to use polymer composite with either 85 or 90 weight percentage of PP/ABS (Table V) if high impact strength is required as they exhibit the highest impact strength and absorb more energy per unit area compared to others.

E. Scanning Electron Microscopy

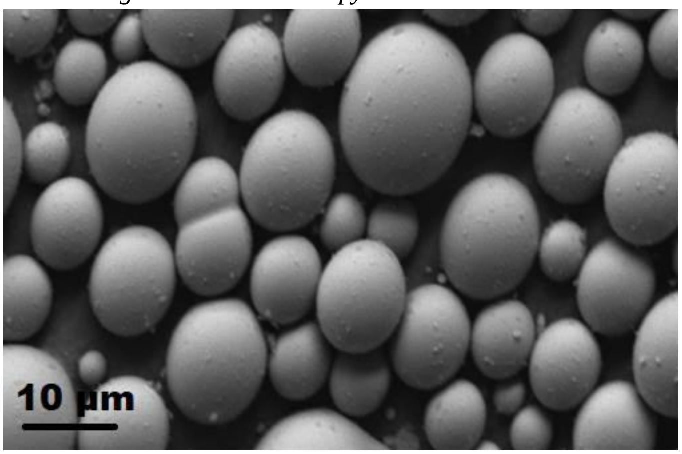

Fig. 9 SEM image of hollow glass microspheres (HGM)

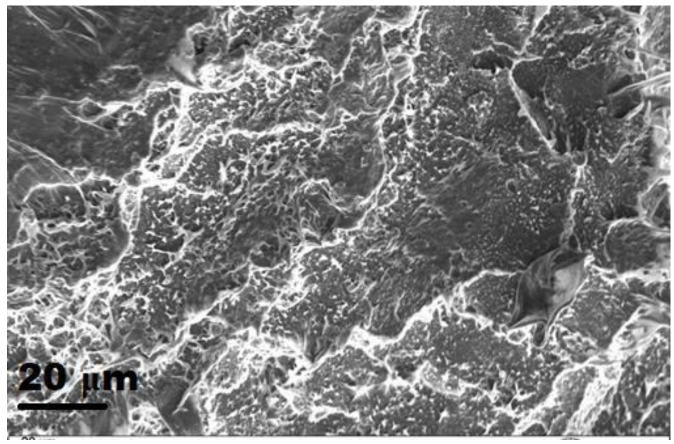

Fig. 10 SEM image of fractured PP/ABS specimen

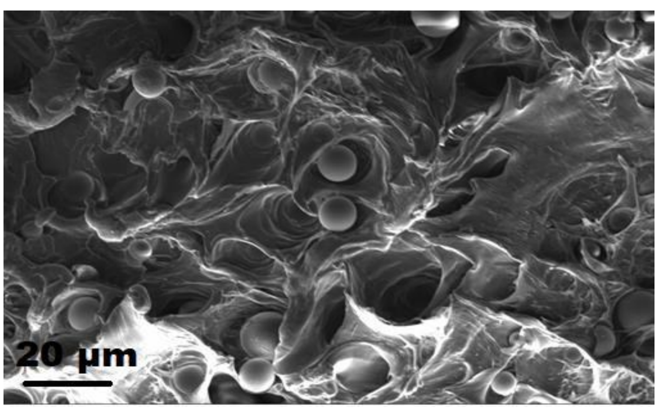

Fig. 11 SEM image of fractured PP/ABS +5% HGM specimen

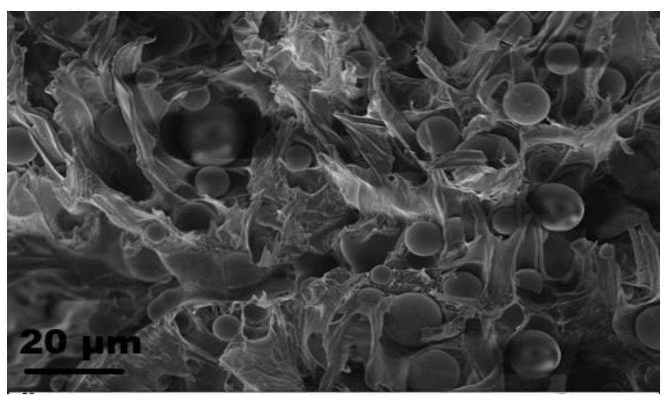

Fig. 12 SEM image of fractured PP/ABS +20% HGM specimen

Fig. 9 HGM's SEM micrograph is shown. The morphological characteristics of these HGMs are spheres with smooth surfaces and average diameters ranging from 10 to 50 m.The fractured surfaces of the HGM reinforced with PP/ABS composite were SEM-ed to investigate the HGM-PP/ABS interaction and the microstructural changes that occur when HGM is incorporated into the PP/ABS matrix. The fractured surface of the pure PP/ABS specimen was micrographed (Fig. 10), The fracture has been observed to be brittle in nature.The fractured surface is smooth with very little roughness.The SEM micrographs of the HGM/PP/ABS composite show that the HGM has good contact with the PP/ABS matrix (Fig. 11 and 12). The morphology of the fractured surface changes dramatically after the HGM content is introduced. In the presence of HGM, the smoothness of the fractured surface decreases, indicating a brittle to ductile transformation in the composite matrix.

IV. CONCLUSIONS

A. In this work, the effect of addition of hollow glass microspheres to PP/ABS matrix was studied .Because of the hollow structure of hollow glass microspheres, samples with a higher weight percentage of hollow glass microspheres have a lower density than those with a lower weight percentage.
B. Tensile stress at break decreases as the weight percentage of hollow glass microspheres increases in PP/ABS matrix.
C. The composite has a maximum value of Young's Modulus when weight percentage of hollow glass microspheres is 20% in the composite.
D. Value of true strain at maximum load is higher in sample having 10 percentage of hollow glass microspheres in the PP/ABS matrix.
E. SEM micrographs of the composite show that the hollow glass microspheres make good contact with the PP/ABS matrix. With the addition of hollow glass microsphere content, there is a significant and noticeable difference in the morphology of the fractured surface's surface.
F. The presence of hollow glass microspheres reduces the smoothness of the fractured surface, implying a brittle to ductile transformation in the composite material.

V. ACKNOWLEDGMENT

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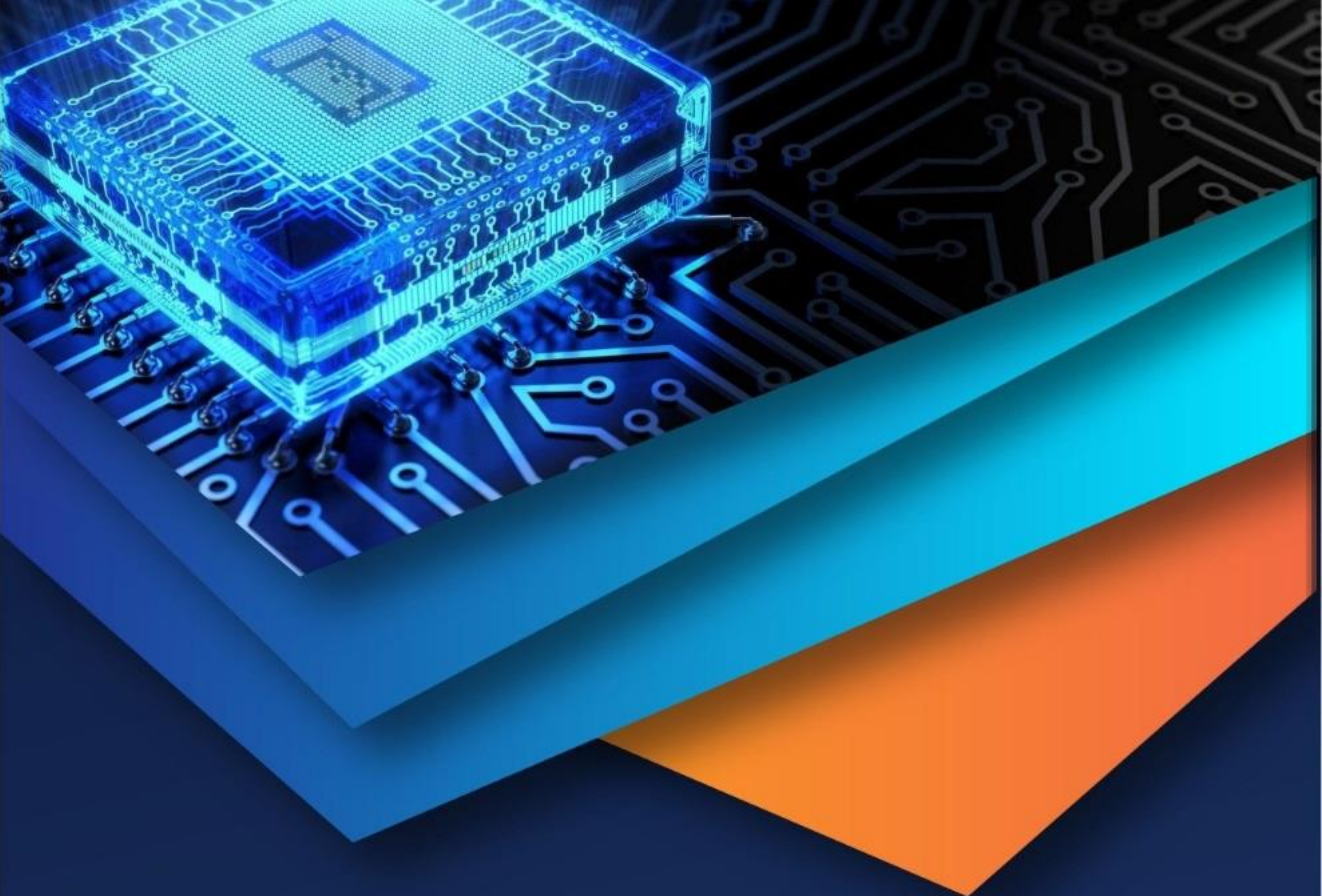

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