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AN EXPERIMENTAL INVESTIGATION ON THE DEVELOPMENT OF SAW DUST POLYMER COMPOSITE FOR DOOR SHUTTER APPLICATION AS A SUBSTITUTE TO NATURAL WOOD

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ABSTRACT

Insulated paper board saw dust waste from paper board industries is used to develop composite materials for its application as door shutter. Physical and mechanical analysis of the developed composite is carried out and presented along with optimized process parameters. Developed composite is analysed for its density, porosity, water absorption, compressive strength, tensile strength and screw withdrawal properties. Observed behaviour is explained and it is found that this waste can be successfully used for the development of composites. This has its potential application as door shutter in building industry, and can be used as a substitute to natural wood.

Keywords: Composite; waste to wealth; polymer, building material; mechanical properties.

1. INTRODUCTION

Insulated paper board saw dust (IPBSD) is a waste material and does not posses any commercial value except for fuel after briquetting. Hence, an attempt is made herein to develop a composite for the fruitful use of IPBSD waste for door shutters applications in building industry. The present investigation is aimed to study (i) effect of moulding pressure on density for different compositions of saw dust and polymer, (ii) effect of moulding pressure on water absorption capacity, (iii) effect of polymer content on compressive strength of the developed composite, (iv) effect of polymer content on screw withdrawal force of the developed composite, and (vi) effect of moulding pressure on tensile strength of the developed composite along with the effect of addition of fly ash.

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2. METHODOLOGY AND MATERIALS

The raw materials used for production of IPBSD waste polymer composite are saw dust waste, polymer and fly ash. In the present investigation, quantity of polymer content is varied from 25-40 % by weight, insulation paper saw dust content is varied from 40-75 % by weight, and fly ash content is varied from 0-20 % by weight. This composition is decided based on the previous experience wherein polymer is used as binder and fly ash as pore refiner [1]. The polymer is unsaturated polyester resin with viscosity of 15 Poise at 25 ± 2°C and acid No. 2 mg KOH/g with slow flammability potential. It was used along with Cobalt Napthonate as accelerator and Methyl Ethyl Ketone Peroxide (MEKP) as catalyst. IPBSDPC samples were collected in a bulk (~20 kg) from a dumping yard situated in the premises of M/S EVONNE, Sector H, Govindpura Industrial Area, Bhopal, India. The specific gravity, bulk density, voids and pH of IPBSD is 1.626, 0.286 g/cm^3, 82.42 %, 6.9, respectively. All this analysis is carried out as per standard methodology [2-4]. The fly ash was procured in bulk for experimentation purpose from M/S HEG, Mandideep, Bhopal, India. Table1 shows the physical and chemical properties of fly ash used as filler in the present investigation [5].

Table 1: Physical and chemical properties of Fly Ash

	Physical properties		
1	Specific gravity	2.142	
2	Bulk density	1.106	g/cc
3	Voids	48.37	%
4	pH	7	
5	Grain size distribution		
	D10	1.19	μm
	D30	6.42	μm
	D60	18.18	μm
	D100	88.91	μm
	Coefficient of Curvature, C_c	1.9	
	Coefficient of Uniformity, C_u	15.27	
	Chemical properties		
1	Silica (SiO_2)	57.24	%
2	Alumina (Al_2O_3)	20.42	%
3	Iron Oxide (Fe_2O_3)	6.28	%
4	Calcium Oxide (CaO)	5.8	%
5	Magnesium Oxide (MgO)	1.12	%
6	Potassium Oxide (K_2O)	2	%
7	ZnO	1.46	%
8	PbO	< 0.1	%
9	CuO	< 0.1	%
10	Loss on Ignition (LOI)	~5.68	%

3. PROCESS PARAMETER OPTIMIZATION

The parameters for optimization of processes required in the production of insulating paper board saw dust waste polymer composite are studied prior to final production of composite samples used for the strength evaluation.

3.1 Optimum moulding pressure

In the present investigation, IPBSD polymer composite (IPBSDPC) are produced using pressure-moulding technique and therefore moulding pressure is one of the important factors which need to be optimized. Moreover, its relation with density is established experimentally, wherein the moulding pressure was varied between 60 kg/cm^2 to 100 kg/cm^2, at an interval of 10 kg/cm^2. The polymer content was varied from 25 % to 40 % by weight of matrix. For this experimental investigation, four sets of experiments are taken into consideration for producing IPBSDPC. The blends have 25 %, 30 %, 35 % and 40 % polymer content with 75 %, 70 %, 65 % and 60 % waste, respectively. The experimental results of moulding pressure and achieved density for the developed IPBSDPC are presented in Fig. 1 (a). It can be observed from Fig. 1 (a), that the density is increasing with increase in pressure. Further, it is observed that with increase in polymer content, rate of increment in density is reduced significantly. Specially, in case of 100 kg/cm^2 pressure, the polymer squeezes out from the matrix for 35% and 40 % polymer content samples. However, in case of 60 kg/cm^2, 70 kg/cm^2, 80 kg/cm^2 and 90 kg/cm^2 moulding pressure, the increase in density is observed, but beyond 90 kg/cm^2 pressure, there was no appreciable increase in density. Hence, the moulding pressure of 90 kg/cm^2 is said to be as maximum optimum moulding pressure for this composite and polymers combinations considered in the present investigation. It is also to be noted that, at this optimum moulding pressure, demolding was normal as well as the quality of composite based on visual observation was excellent for all the compositions considered in the present investigation.

3.2 Ensuring pressure uniformity

It is of utmost importance that pressure should be applied uniformly for the development of good composite. In order to achieve and maintain it experimentally; the two set of experiments were designed (with 35 % and 40 % resin content) for moulding composite of different weight using same blend.

For proper moulding, moulding pressure is kept constant (i.e. 90 kg/cm^2) and two sets of polymer contents i.e. 35 % and 40 % by weight of matrix is adopted. The experimental results of pressure uniformity test for IPBSDPC are reported in Fig. 1 (b). It can be concluded from the study that the composite produced for different thickness have the uniform density. It is concluded that for production of composite, the quantity of material used is not having any dependency over moulding pressure. In the present investigation, two sizes of composite i.e. 100 mm × 50 mm × 50 mm and 190 mm × 90 mm × 90 mm are developed and from these different specimen were prepared. The composite were made using pressure moulding technique up to 90 kg/cm^2 moulding pressure in steel die.

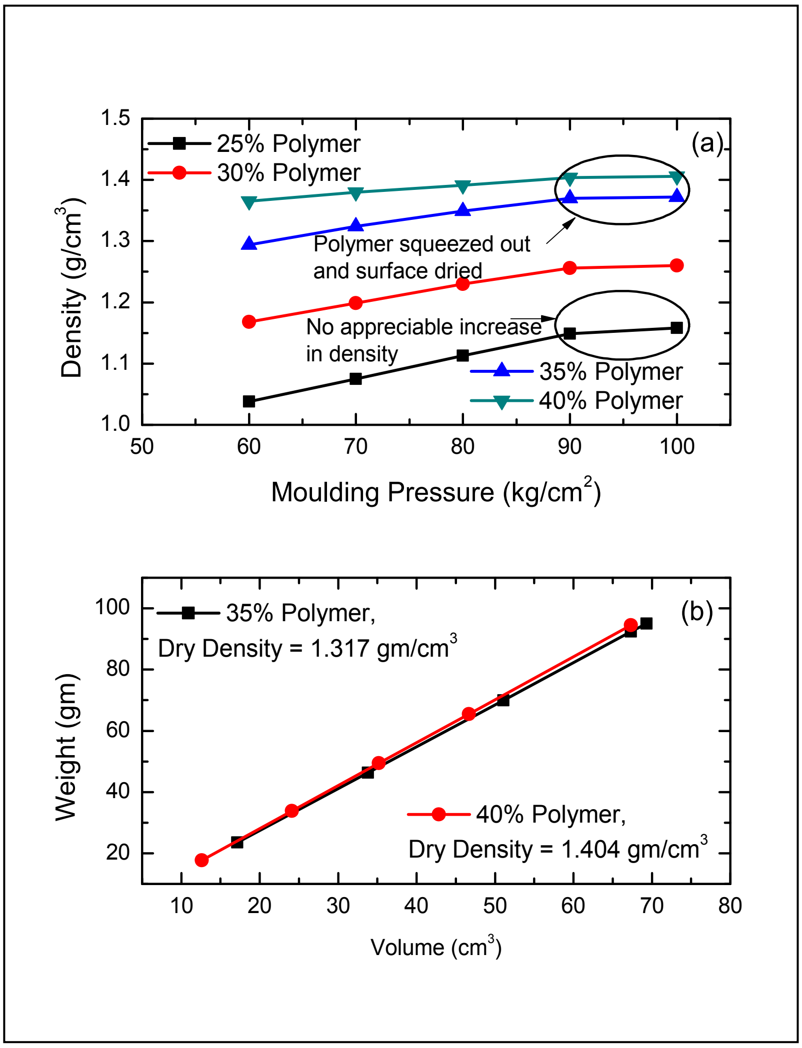
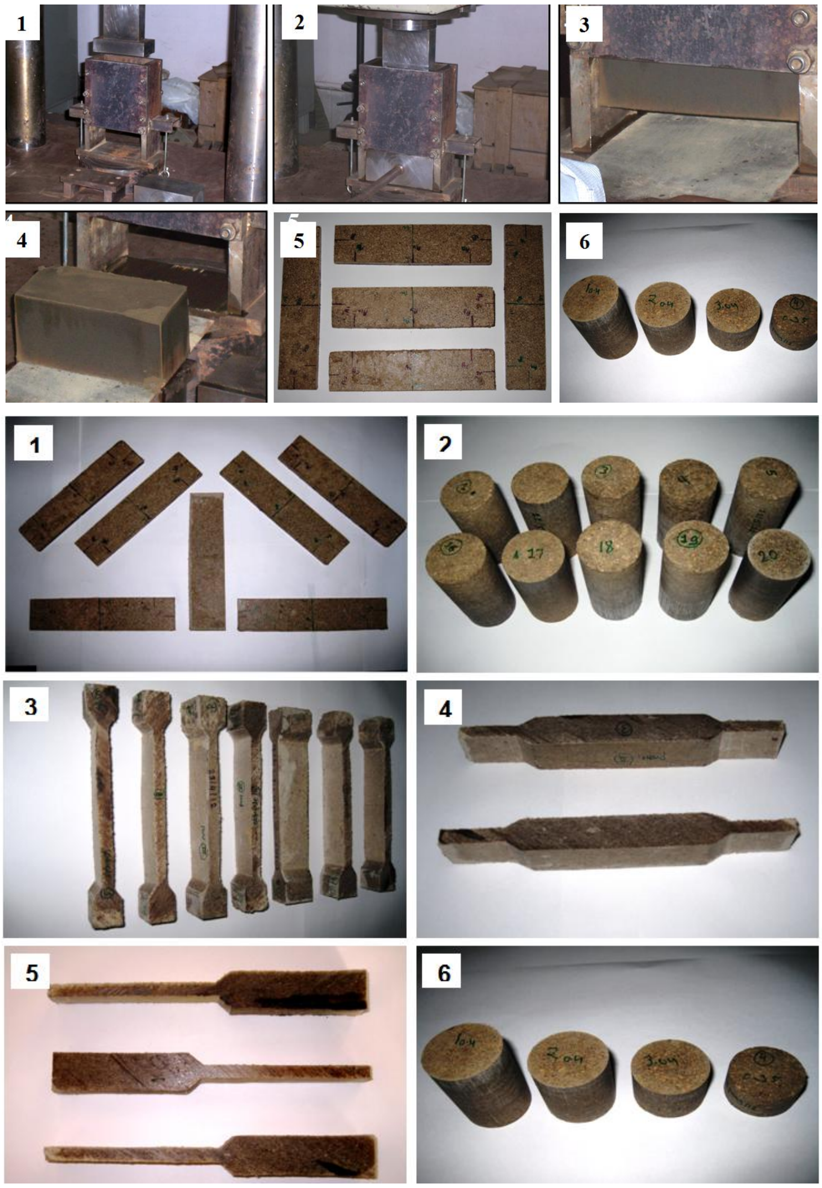


Figure 1. (a) Effect of moulding pressure on density for different compositions of IPBSDPC (b) Weight v/s volume of composite for IPBSDPC

4. PRODUCTION OF IPBSDPC

The mass scale production of IPBSDPC was done using die of 190 mm × 90 mm × 90 mm size. The composite prepared for experimentation purposes were decided post cure in an oven at 65°C temperature for 6 hours duration. The different stages in the manufacture of IPBSDPC are presented in Fig. 2 (a). The stages involve (1) installation of the die (2) compression of the matrix (3) ejection of the composite (4) removal of the composite (5) composite, and (6) post cured finished composite. The physical properties i.e. dimensions, density, volumetric expansion, compressive strength, water absorption, and tensile strength, screw withdrawal strength were measured for IPBSDPC using the standard procedures. Fig. 2 (b) shows the different shapes of the moulded composite, which is used in characterization of various properties of the developed composite.



(a)

(b)

Figure 2. (a) Different stages in the manufacturing of IPBSDPC (b) Different shapes of IPBSDPC used for characterization of properties

5. RESULTS AND DISCUSSIONS

For complete experimental program, a total of 118 specimens of size 190 mm × 90 mm × 90 mm were prepared for IPBSDPC. The experiments divided into two cases, first case from IPBSDPC-1 to IPBSDPC-4 is having polymer content (25 %, 30 %, 35 % and 40 %) and remaining will be the IPBSD (75 %, 70 %, 65 % and 60 %) by weight. In second case, IPBSDPC-5 to IPBSDPC-9, the fly ash content is 20% and polymer contents varies (30 %, 32.5 %, 35 %, 37.5 % and 40%), and rest is IPBSD. In order to study the effect of moulding pressure, the moulding pressure was varied from 60-90 kg/cm^2 for the first case (without fly ash), whereas 70-100 kg/cm^2 for second case (with flay ash). The post curing of IPBSDPC was done by heating at 65^{o}C for 6 hours duration. After completing the post curing, the physical and mechanical properties were measured. The include dimension and density, volumetric expansion, water absorption and porosity, compressive strength, tensile strength, screw withdrawal strength and pH values were evaluated and discussed herein.

5.1 Bulk density of IPBSDPC

In case of IPBSDPC, the bulk density of composite is measured after post curing of the specimens, because after post curing the polymer gets completely cured resulting in dense composite. The change in bulk density with variation in polymer content as well as moulding pressure is reported in Fig. 3(a) and Fig. 3(b), respectively. It can be observed from Fig. 3(a) and Fig. 3(b) that, the bulk density of the composite varies with compositional changes. In case of IPBSDPC-1, IPBSDPC-2, IPBSDPC-3 and IPBSDPC-4, the bulk density increases with increase in polymer content. Similarly, the density increases with increase in polymer content. Further, composite made with polymer content varying from 25 % to 40 %, the variation in bulk density observed are 1.038 g/cm^3 to 1.404 g/cm^3 after post curing at 65 °C for 6 hours duration.

Similar observations were made in case of composite made using different combinations of polymer, fly ash and IPBSD. The variations in bulk density were observed 1.066 g/cm^3 to 1.419 g/cm^3. The change in density due to moulding pressure effect is significant. Also, the changes are considerable with the change in quantity of polymer. When, polymer content was kept constant at 40%, and varying the moulding pressure from 70 kg/cm^2 to 100 kg/cm^2, the bulk density varied from 1.292 g/cm^3 to 1.419 g/cm^3. Similarly, the composite were made using moulding pressure 100 kg/cm^2, fly ash content at 20 %, by varying polymer content from 30 % to 40 % and the bulk density varied from 1.169 g/cm^3 to 1.419 g/cm^3.

5.2 Water absorption of IPBSDPC [6-7]

The water absorption is measured for all the samples of IPBSDPC after completing the curing period. The methodology followed for measuring the water absorption is as per IS 3495 (Part-III) - 1976 and ASTM C67-13 [6-7]. The change in water absorption with moulding pressure is computed for post cured specimens and results are reported in Fig. 3(c) and Fig. 3 (d), respectively for two cases of IPBSDPC considered in the present investigation.

It is observed that the water absorption of the composite vary with compositional changes, it decreases with increase in moulding pressure, and polymer content. The change in water absorption due to moulding pressure, and polymer content is significant. The decrease in water absorption with the increase in moulding pressure is attributed to the blockage of fine pores resulting in reduction of water absorption. In case of IPBSDPC-1 to IPBSDPC-4, the polymer content varied from 25 % to 40 %, the variation in water absorption observed was 1.25 % to 34.48 %. It infers from Fig. 3(c) and Fig. 3(d) that the water absorption is high in case of composite produced with less polymer contents, due to poor gluing of the particles in matrix. It can be seen from the Fig. 3(c) and Fig. 3(d) that the water absorption decreases with increase in moulding pressure and polymer content, but rate of decrease is very significant. When, the composite made with 40% polymer content, 20% fly ash and rest with IPBSD, the water absorption varies from 3.65 % to 1.19 % with increase in moulding pressure from 70 kg/cm^2 to 100 kg/cm^2. Similarly, if polymer content varies from 30 % to 40 % and moulding pressure kept constant at 70 kg/cm^2, the water absorption varied from 28.94 % to 3.65 %. It means, the role of polymer content as well as moulding pressure is very significant for making good composite.

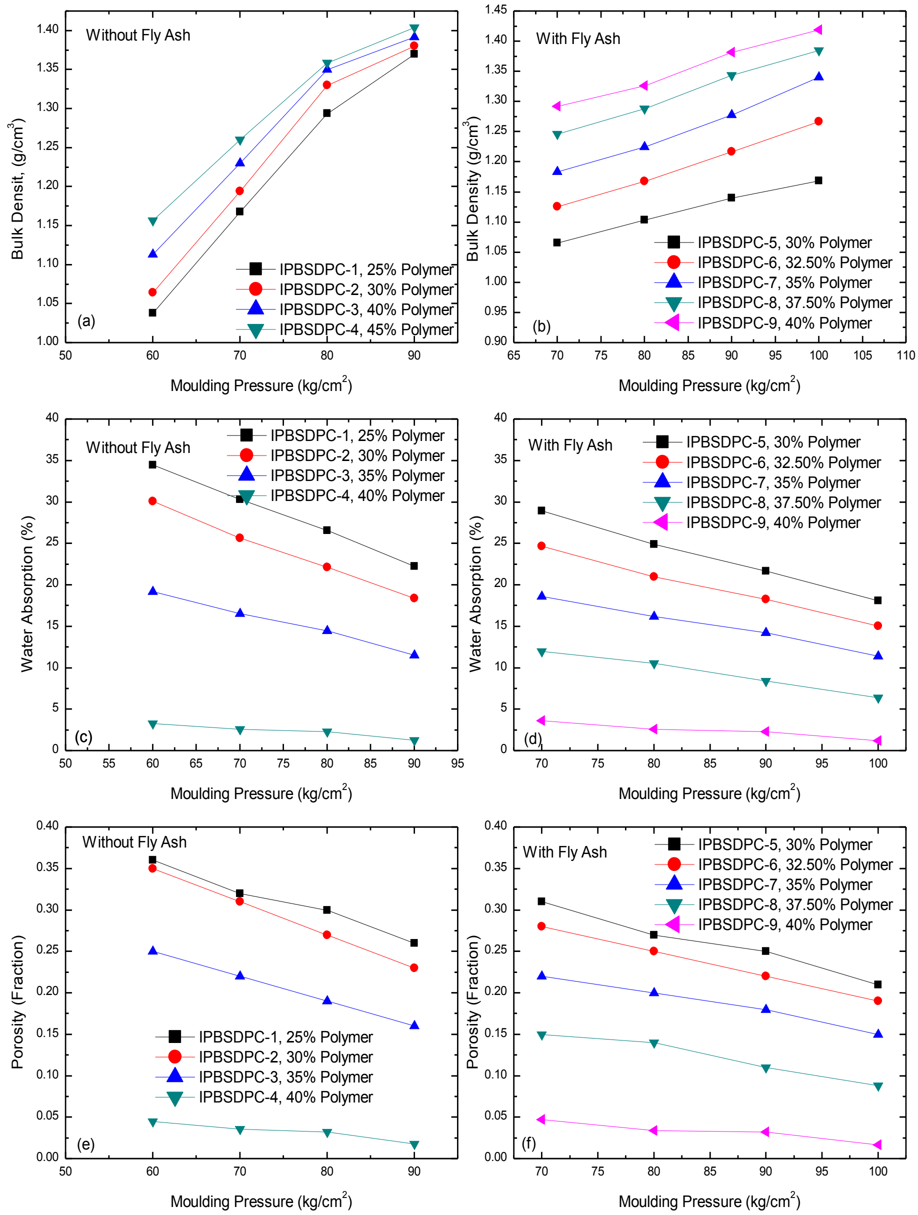


Figure 3. Effect of Moulding Pressure on (a) Bulk Density of IPBSDPC without Fly Ash (b) Bulk Density of IPBSDPC with Fly Ash (c) water absorption of IPBSDPC without Fly Ash (d) water absorption of IPBSDPC with Fly Ash (e) Porosity of IPBSDPC without Fly Ash (f) Porosity of IPBSDPC with Fly Ash

5.3 Porosity of IPBSDPC

The porosity was measured for all the specimens of IPBSDPC after completing the post curing as per IS 3495 (Part-III) - 1976 and ASTM C67-13 [6-7]. The changes in porosity with moulding pressure were computed for composite without and with blending of fly ash and results are shown in Fig. 3(e) and Fig. 3(f), respectively.

It is observed that the porosity of the composite varied with compositional changes, which decreased with increase in polymer content. The moulding pressure has significant effect on porosity. The decrease in porosity with the increase in polymer content is due to the enough gluing material in a composite, resulting blockage of fine pores and subsequent reduction in porosity. In case of IPBSDPC-1 to IPBSDPC-2, the polymer content varies from 25% to 40 %, the variation in porosity observed was 0.36 to 0.018 fractions. It is seen from the Fig. 3(e); the porosity is high in case of composite produced with less polymer content. In case of IPBSDPC-1, the variation in porosity was observed from 0.36 to 0.26 fractions. When, moulding pressure was kept constant to 90 kg/cm^2, the porosity varies from 0.26 to 0.018 fractions. It can be seen from the Fig. 3(f) that the porosity decreased with increase in moulding pressure as well as polymer content. The porosity of composite is dependent on moulding pressure and polymer content. The porosity of composite varied from 0.31 to 0.017 fractions, when composites were having polymer content 30 % to 40 % and fly ash content 20 % by weight, respectively. In case of polymer content of 40 %, fly ash content as 20%, by varying the moulding pressure from 70 kg/cm^2 to 100 kg/cm^2, the porosity varied from 0.049 to 0.017 fractions. Similarly, if moulding pressure kept constant at 100 kg/cm^2, and the polymer content varied from 30 % to 40 %, the porosity varies from 0.21 to 0.017 fractions.

5.4 Compressive strength of IPBSDPC

The compressive strength is measured as per standard procedure for all the specimens of IPBSDPC after completing the post curing [8]. The changes in compressive strength with polymer content were computed and results are shown in Fig. 4 (a) and Fig. 4 (b). It is observed that the compressive strength of the composite varied with increasing rate with compositional changes, it is increasing with increase in polymer content, and the effect is significant. In case of IPBSDPC-1 to IPBSDPC-4, the polymer content varies from 25 % to 40 %, the variation in compressive strength observed was 323 kg/cm^2 to 1388 kg/cm^2. During moulding of composite, the moulding pressure varied from 60 kg/cm^2 to 90 kg/cm^2. It is seen from the Fig. 4 (a), the compressive strength is low in case of composite produced at low moulding pressure. In case of IPBSDPC-11 to IPBSDPC-41, the variation in compressive strength is observed from 323 kg/cm^2 to 1329 kg/cm^2 after post curing. When, polymer content was kept constant at 25% by weight, and without fly ash, the compressive strength varied from 323 kg/cm^2 to 560 kg/cm^2. Similarly, the composite were made at moulding pressure 90 kg/cm^2, by varying polymer content from 25% to 45%; the compressive strength varied from 1329 kg/cm^2 to 1388 kg/cm^2, respectively. It shows that the moulding pressure is very significant in making good composite, and the effect of varying polymer content is not so much significant. In case of IPBSDPC-5 to IPBSDPC-9, the polymer content varies from 30 % to 40 %, fly ash content 20 %, and the moulding pressure varied from 60 kg/cm^2 to 90 kg/cm^2. The variation in compressive strength observed was 578 kg/cm^2 to 1480 kg/cm^2. Fig. 4 (b) shows that the moulding pressure is very significant as compare to polymer content. It is seen from the results that, the compressive strength was comparable, when composite were made at 100 kg/cm^2 moulding pressure. When, polymer content was kept constant at 40 % by weight, and with fly ash, the compressive strength varied from 736 kg/cm^2 to 1480 kg/cm^2. Similarly, the composite were made at moulding pressure 100 kg/cm^2, by varying polymer content from 25 % to 40 %; the compressive strength varied from 1467 kg/cm^2 to 1480 kg/cm^2, respectively. At high pressure moulding, the excess polymer bleeds out after complete filling of pores, as a result of it the variation in compressive strength is very minute.

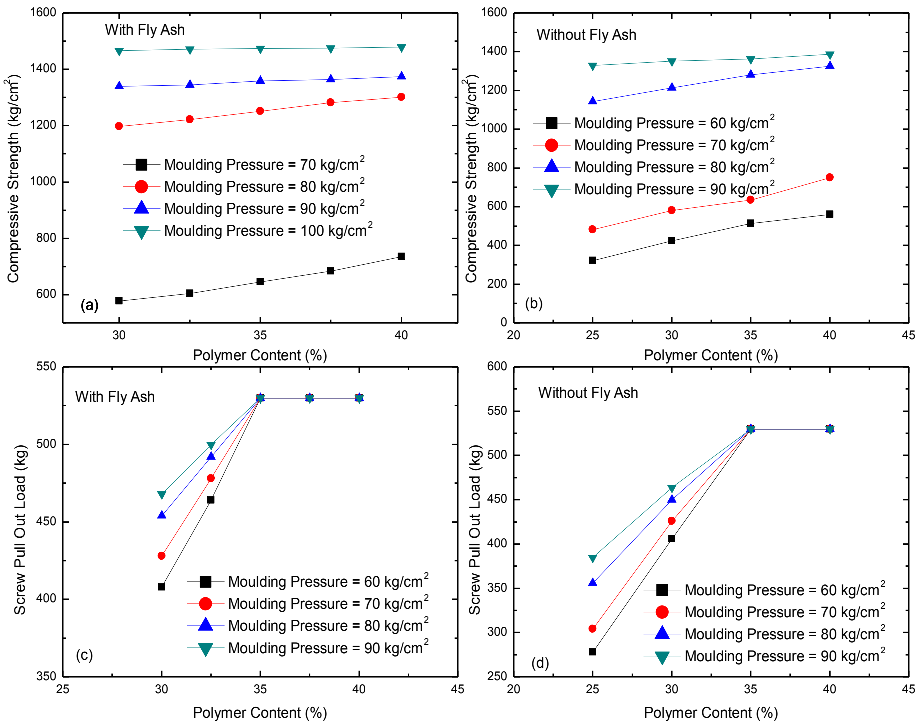


Figure 4. Effect of polymer content on (a) Compressive strength of IPBSDPC with Fly Ash (b) Compressive strength of IPBSDPC without Fly Ash (c) Screw pullout strength of IPBSDPC with Fly Ash (d) Screw pullout strength of IPBSDPC without Fly Ash

5.5 Screw pullout strength of IPBSDPC [9]

The screw pullout strength of composite measured for all the compositions i.e. IPBSDPC-1 to IPBSDPC-4. It can be seen from Fig. 4 (c) and Fig. 4 (d), that the composite made with 35 % and 40 % polymer content, have no screw pullout, but screw fails due to its ultimate tensile strength at 530 kg failure load. In case of 25 % and 30 % polymer content, the pull out load required 278 kg to 442 kg for specimen produced at moulding pressure 60 kg/cm^2 to 90 kg/cm^2, respectively. The similary observations were made for all the compositions i.e.

IPBSDPC-5 to IPBSDPC-9. It can be seen from Fig. 4 (d), that the composite made with 35 %, 37.50 % and 40 % polymer content, have no screw pullout, but screw fails due to its ultimate tensile strength at 530 kg failure load. In case of 30 % and 32.50 % polymer content, the pull out load required 408 to 500 kg for specimen produced at moulding pressure 60 kg/cm^2 to 90 kg/cm^2, respectively. For screwing the higher polymer content compositions, high tensile strength screws are required.

5.6 Tensile strength of IPBSDPC [10-11]

The tensile strength of composite, produced from 35% and 40 % polymer content, and moulded at 90 kg/cm^2 and 100 kg/cm^2 were measured. We observed that the flyash filled composite are having less strength as compare to unfilled. The results are shown in Fig. 5. It can be seen from Fig. 5, that the composite made at 90 kg/cm^2 moulding pressure, with 35 % and 40 % polymer content, the tensile strength varied from 64 kg/cm^2 to 76 kg/cm^2 and 140 kg/cm^2 to 162 kg/cm^2 for with and without flyash filled composite, respectively. Similarly, in case of 100 kg/cm^2 moulding pressure, the tensile strength varied from 78 kg/cm^2 to 92 kg/cm^2 and 165 kg/cm^2 to 184 kg/cm^2 for with and without flyash content, respectively.

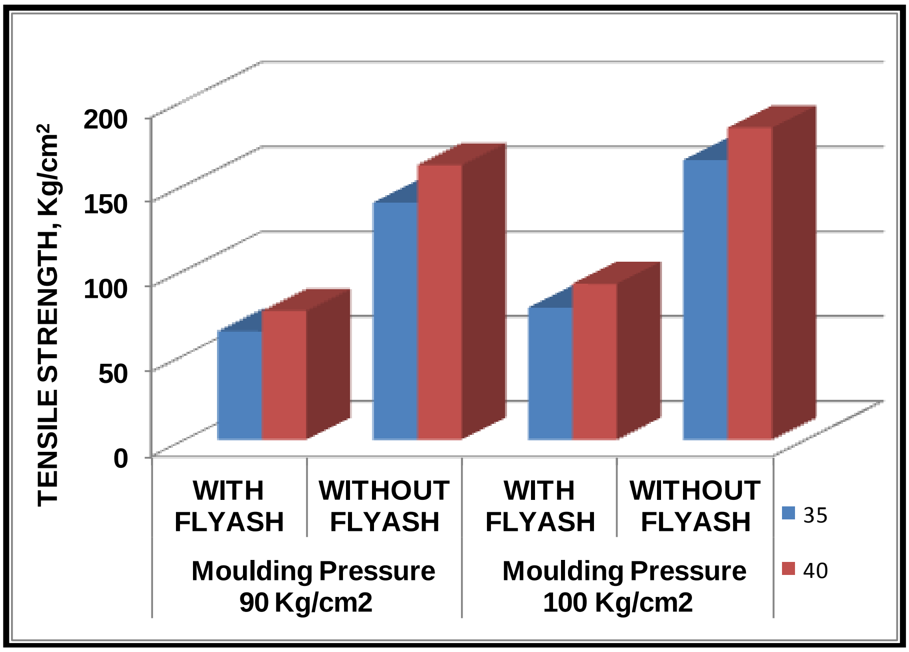


Figure 5. Effect of fly ash and polymer content on tensile strength of IPBSDPC

6. CONCLUSIONS

In the present study IPBSD is used along with other suitable ingredients viz. polymer and fly ash for making the composites. Two types of composites are made i.e. IPBSDPC with and without fly ash. For detailed characterization, nine compositions/blends are considered, which are designated as IPBSDPC-1 to IPBSDPC-9. On the basis of present investigation following conclusions are drawn:

1. The bulk density varies from 1.038 to 1.419 g/cm^3, when moulding pressure varied from 60 kg/cm^2 to 100 kg/cm^2. The bulk density increases with increase in moulding pressure at the higher rate in case of lower polymer content, but the rate of increase is lowered as the polymer content is increased.
2. When the fly ash is not incorporated in to the matrix, and polymer content is varies between 25 % to 40 % by weight, the bulk density varies from 1.038 g/cm^3 to 1.404 g/cm^3 with moulding pressure varying from 60 kg/cm^2 to 90 kg/cm^2. In case of 20 % fly ash incorporation into the matrix, the bulk density varies from 1.066 g/cm^3 to 1.419 g/cm^3, with variation in moulding pressure from 70 kg/cm^2 to 100 kg/cm^2.
3. The decrease in water absorption with the increase in moulding pressure is due to the compaction, resulting in reduction in pore size. The reduction in water absorption is observed also due to increase in polymer content and incorporation of fly ash in to the matrix.
4. When the polymer content increased from 25 % to 40 % by weight, the decrease in water absorption of composite is noticed and the decreasing trend is linear varying from 34.48 % to 1.19 %.
5. It is observed that the porosity of the composites decreases with increase in polymer content and fly ash content in the matrix. The change in porosity due to moulding pressure is found to be significant.
6. When the polymer content is increases from 25 % to 40%, the decrease in porosity of composite is noticed from 0.36 % to 0.017 %.
7. When the polymer fraction is increased from 25 % to 40 %, the increase in compressive strength of composite is noticed from 323 kg/cm^2 to 1388 kg/cm^2. In case of 20 % fly ash blending into the matrix and polymer content varying from 30 % to 40 %, the increase in compressive strength is observed from 406 kg/cm^2 to 1480 kg/cm^2.
8. The pH value of composite is found to be 6.9, which is near to the neutral.
9. The screw pull-out strength of IPBSDPC increases with increase in polymer content up to 32.5% of the composite and varies from 278 kg to 500 kg. Beyond, 32.5 % polymer content, screw could not pull out, but it failed, which is attributed to screw ultimate tensile strength itself being 530 kg.
10. In case of without fly ash mixing in to the matrix, the tensile strength is 140 kg/cm^2 and 184 kg/cm^2, respectively, for 35 % and 40 % of polymer content. Whereas, in case of fly ash blended specimen, the strength is 64 kg/cm^2 to 92 kg/cm^2 respectively.

It is concluded that the Insulated Paper Board Saw Dust Polymer Composites (IPBSDPC) are promising building material for manufacturing door shutters for the building material industry as a substitute to natural wood.

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