RESEARCH ARTICLE OPEN ACCESS

Hygroscopic and Rheological properties of sustainable Dalbergia sissoo Wood Flour on Recycled/Virgin Polypropylene Composites with/without MAPP

Gaurav Verma[1] Dr L P Singh[2] Anil Kumar Yadav[3] Dr P B Patel[4]
1 MTech, Sam Higginbottom University Of Agriculture Technology And Sciences, Allahabad
2 Assistant Professor, Sam Higginbottom University Of Agriculture Technology And Sciences, Allahabad
3 Research scholar, Motilal Nehru National Institute of Technology Allahabad
4 Assistant Professor, Chhatrapati Shahu Ji Maharaj University, Kanpur

Abstract:
This study scrutinizes, the influence of wood sawdust *(Dalbergia sissoo)* as filler on hygroscopic and rheological properties of composite produced by using it with recycled/virgin polypropylene *(PP)*. In this research, wood sawdust of 200-250µm was compounded in the form of pallets using twin screw extruder for which the composites of PP matrix 80, 70, 60 and 50 wt% was used. These pallets were then fabricated into the specimen by injection moulding method with altering formulations based on the synthetic polymer type (PP), synthetic polymer form (recycled and virgin), wood sawdust content and inclusion of coupling agent(MAPP). The result exhibits that recycled polypropylene (RPP) based WPCs shows better water absorption and thickness of swell than composite based on virgin polypropylene (VPP). The maleated polypropylene (MAAP) improves the dimensional stability of the WPCs remarkably when incorporated in small concentration of 3-5 wt% in the formulations. The Scanning electron microscopy (SEM) analysis of tensile-fractured surfaces of the specimen clarifies the aftermath of reprocessing in WPCs and improvement in interfacial bonding due to presence of the coupling agent (MAPP).

Keywords — **Wood Plastic Composite, Wood Sawdust, Virgin And Recycled Polypropylene, Water Absorption, Thickness Of Swell, MFI, SEM.**

I. INTRODUCTION

Now a day's world is going through a serious problem of plastic waste disposal as it increasing with the alarming rate and effecting to the environment to the great extent. The polymeric waste accumulated by the world is about approximately 100 million ton per annum of which total waste generated by India is about approximately 15342 tons/day by both domestic as well as industrial application. This waste plastic is either disposed of in landfill (22-43%) or end up in ocean (10-20 million tons approx) each year. In the similar way, waste wood is generated in large amount at the different step of wood processing mainly use as energy resource. This dumping of solid waste results in production of harmful gases[1-5]. One possible measures for the solid plastic waste problem is the recycling procedure[6].The recycling of the post consumed polymeric waste reduce solid waste disposal problem, decline the virgin plastics utilization and minimize the cost of production. Recycling improves the intermolecular linking of the polymer, which affect the properties of polymer which makes different from its source material. The production of wood plastic composites (WPCs) by consumption of the waste plastic makes it economical[7]. Amenable investigation has been performed on distinguishing the WPCs but investigation on reprocessing polymer matrix is quiet less. In few decades the use of wood fibres/flour for reinforcement of plastic has increased drastically[8-9].Different Thermoplastic which are generally used for fabrication of composites are LDPE , HDPP, LDPE, HDPE, PVC ,PS and many more. WPCs are mixture of wood and plastic having ratio 50:50 by weight[10]. Wood and plastic are solely diverse in nature, plastic are hydrophobic and wood are hydrophilic in nature. Therefore, the adhesion between wood and plastic is very less, which affect greatly properties of WPCs. The adhesion between the wood particle and polymer can be improved to a great extent by adding the coupling agent in small quantity 0-5% which enhances the properties of WPCs [11].Different additives which are mainly used in fabrication of composites such as EPOLE, E-43, Talc, MAPP, and many more. Coupling agent increases the intermolecular linking between polymer and wood, which diminishes the water absorption by proper nucleation of the wood particles and improves the mechanical properties of the WPCs [12].Bledzki et al., [10] has explored the different compounding techniques, specifically twin-screw extruder, high-speed mixer and two-roll mill. It was concluded that the twin-screw extruder compounded composites had better results from those that compounded in a two-roll mill or a high-speed mixer. Migneault et al., [13] reported that the effects of fibre size and processing method on the properties of composites. It was found that the Injection moulding process shows low water uptake than extrusion process whereas Fiber L/D ratio resulted in decreased water uptake characteristics. Tamrakar et al., [14] studied the water uptake and durability of Z-section sheet piles made from extruded wood polymer polypropylene composites.The water uptake followed the kinetics of a Fickian diffusion process. In 28 days of immersion, water became more turbid and dark and surface of specimen became oily along with water. Sarabi et al., [15] investigated that the properties of the recycled composites of high density polyethylene (HDPE) and wood sawdust with different melt flow indices (MFIs). The composites produced with the middle MFI HDPE shows low water absorption behavior among all. Kord et al., [7] investigated water uptake and thickness swelling of composites fabricated from virgin and/or recycled plastics, namely high density polyethylene and polypropylene with pine wood dust in different ratio by weight. It was found that the water uptake and thickness swelling of WPCs containing polypropylene is lower than those of polyethylene. Bhaskar et. al.,[16] has fabricated using matrices of recycled polypropylene (RPP) and virgin plastic (VPP) with Pine wood flour as filler. They fabricated it through melt compounding and injection moulding in different weight ratio and addition of coupling agent (MAPP). They found that the coupling agent (MAPP) can significantly reduce the water absorption. Haq et al.,[17] elaborated that the WPCs produced by recycled/virgin PP with wood flour filler, RPP composites show low water uptake and low thickness of swell than VPP based composite. The addition of MAPP in the same formulation decreases the hygroscopic properties of the composites [20].

II. MATERIALS AND METHODS

(1)Thermoplastics

In this study both virgin and recycled polymer of PP are used as matrix. Recycled PP pellet is collected from local recycler Ananta Polyrubb Pvt. Ltd., New Delhi. Virgin PP pellet is collected from the local dealer of Repole (Reliance Polymer). Both the pellets are dried at 70^0C for 24 hr in forced air circulatory oven to remove the moisture content.

(2)Wood saw dust

The *Dalbergia sissoo* dust which was collected from Sardar timber Kanpur works as a reinforced material in the present research .It was dried at 100^0C for 24hr in order to remove the moisture present in wood particles by forced air circulatory. Through sieve analysis the saw dust particle of size 200-250 μm are separated.

(3)Coupling agent

Maleated polypropylene (MAPP) was used as a coupling agent for the fabrication of the WPCs.

(4)Composite Preparation

The wood particles along with/without additives were compounded with virgin/recycled PP granules by twin screw extruder at CIPET laboratory lucknow India. Twin screw extruder the screw speed was of 80 rpm at the barrel pressure of 40 bars had a four heating zone of 170-180-190-200^{0}C. The wire formed compounded material comes out form a die through a bath tub and then cut in the form of pellets through a cutter machine attach with extruder. These pellets were kept for 24 h at 105^{0}C in forced air circulatory in order to remove the moisture. The pellet was fabricated into the testing samples by injection moulding method. The temperature for WPCs sample from feeding zone to die zone was kept at 170°C to 200°C. These samples were made using ASTM D 618-08 (2008) guideline of a temperature of 23 ± 2°C and relative humidity of 50 ± 5%. The composite samples with cooling time about 30 seconds were injected at injection pressure at 45 kg/m². The formulations of the WPCs are given in Table 1-

S.No	Specimen Code	Composition	Plastic type
1	VPP	VPP	virgin
2	RPP	RPP	recycled
3	VPP80W20	20%W+80%VPP	virgin
4	VPP70W30	30%W+70%VPP	virgin
5	VPP60W40	40%W+60%VPP	virgin
6	VPP50W50	50%W+50%VPP	virgin
7	RPP80W20	20%W+80%RPP	recycled
8	RPP70W30	30%W+70%RPP	recycled
9	RPP60W40	40%W+60%RPP	recycled
10	RPP50W50	50%W+50%RPP	recycled
11	50W47VPP3CA	50%W+47%VPP+3%CA	virgin
12	50W47RPP3CA	50%W+47%RPP+3%CA	recycled
13	50W45VPP5CA	50%W+45%VPP+5%CA	virgin
14	50W45RPP5CA	50W%+45%RPP+5%CA	recycled

Table-1 Composite formulation

Figure-1 Fabrication Process of Composite

III. ANALYSIS

(i)Water absorption Test

The water absorption test was performed as per the ASTM D570-98. The specimens were dried in an forced air circulatory at 105^0C for 24hr and then placed in distilled water at the room temperature. The specimens were separated from the water and surface droplets were wiped properly with blotting paper. The test specimens were weighted before and after the water immersion test with the precision of 0.01gm .The amount of water absorption in percentage were calculated using following equation-

$$\boldsymbol{WA}(\%) = \frac{W_f - W_i}{W_i} \boldsymbol{x100}$$

(1)

Where W_i and W_f are the initial and final weight of the specimen after immersion in the water respectively.

(ii)Thickness of Swell examination

Micrometer is used for measuring the TS of the specimen having least count of 0.001mm

The thickness swell (TS) of specimens were measured by using the following equation-

$$\boldsymbol{TS}(\%) = \frac{\delta_f - \delta_i}{\delta_i} \boldsymbol{x100}$$

(2)

Where δ_i and δ_f are the initial and final thickness of the specimen after immersion in the water respectively.

(iii)Melt flow index Test

The Melt flow index test was performed according to ASTM D-1238 by automatically time flow rate measurement. Melt Flow Index (MFI) is define as the measure of a polymer (in grams) flow through a die of specified diameter and length in ten minute by applied gravimetric pressure for given temperature. The MFI has been calculated at applied pressure of 2.16 Kg at the temperature of 230^0C. The experiment is started after loading the compounds and preheating for 1 minute.

(iv)Microstructure Examination

The micro morphology of the fracture surfaces was analysed by scanning electron microscopy (SEM) with the flexural test specimen. A Hitachi scanning microscope operating at an accelerating voltage 15 kV was used for the analysis of the WPCs. Prior to the study, the fractured surfaces were sputter-coater with a layer of gold and analyzed at 500X magnifications.

IV. RESULTS AND DISCUSSION

(i)Water Absorption test

The amount of water absorbed by the WPCs during immersion for 2hr and 24hr is displayed in table (2, 3). Water uptake by all the formulation of PP (recycled/virgin) matrix based composite with and without use of coupling agent (MAPP) were conducted. The water uptake by VPP and RPP during this test were 0.03 and 0.02 in 2hr, similarly 0.06 and 0.05 for 24 hr. The water uptake for VPP matrix based composite varies from 0.08-2.22 for 2hr test and for 24hr test it varies from 0.25-5.56 depending on the composite formulations. In the similar way, the water uptake by RPP matrix based composite in 2 hr varies from 0.07-1.47 and for 24hr period from 0.21-3.87 depending on the composite formulations. The RPP50W50 (50 wt. % RPP and 50 wt. % wood flour) composite exhibited more water absorption than the RPP60W40 composite (60 wt. % RPP and 40 wt. % wood flour).

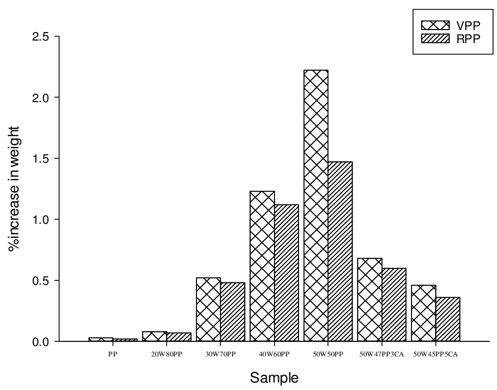


Figure.2 Water absorption of 2hr

Specimen Code	Water absorption After 2hr
VPP	0.03
RPP	0.02
VPP80W20	0.08
VPP70W30	0.52
VPP60W40	1.23
VPP50W50	2.22
RPP80W20	0.07
RPP70W30	0.48
RPP60W40	1.12
RPP50W50	1.47
50W47VPP3CA	0.68
50W47RPP3CA	0.45
50W45VPP5CA	0.6
50W45RPP5CA	0.36

Table-2 Water absorption of 2hr

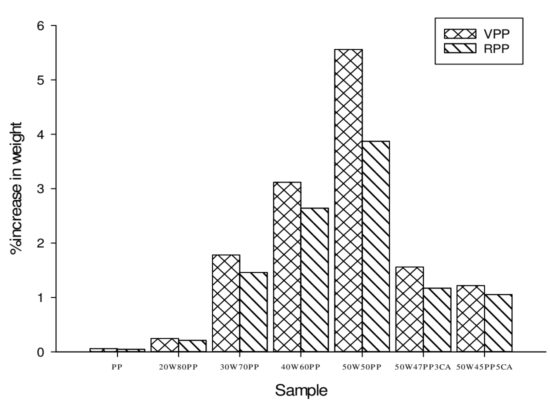


Figure.3. Water absorption of 24h

Specimen Code	Water absorption After 24hr
VPP	0.06
RPP	0.05
VPP80W20	0.25
VPP70W30	1.78
VPP60W40	3.12
VPP50W50	5.56
RPP80W20	0.21
RPP70W30	1.46
RPP60W40	2.64
RPP50W50	3.87
50W47VPP3CA	1.56
50W47RPP3CA	1.22
50W45VPP5CA	1.17
50W45RPP5CA	1.05

Table- 3 Water absorption of 24hr

It was observed that water uptake of the WPCs gradually increased with increase in wood filler in the WPCs. Basically, the water uptake was at the interface of polymer and wood of the WPCs. Both, polymer and wood are distinct in nature so there poor adhesion between wood and plastic which causes more water residence sites in WPCs. The RPP50W50 (50 wt. % RPP and 50 wt. % wood flour) compound exhibit less water absorption than the VPP50W50 (50 wt. % VPP and 40 wt. % wood flour) compound. Recycling of plastic develop at least one ester which creates limpidness in the polymer. This led to increase in the density of plastic and addition of functional group in the composite enhances the adhesion between the two, which considerably minimize the water uptake of the composite. In addition, the RPP50W50/VPP50W50 composite formulation made with 3-5 wt. % MAPP the water uptake is decreases for both the time periods (2h and 24h). This is due to the improvement in the bonding between wood particles and polymer has better interfacial strength and higher density of the composite. It was observed that once the coupling agent is included in the compound, the effect of the wood to polymer proportion is no longer as crucial as in the compound without the coupling agent.

(ii)Thickness of swell

Thickness of swell of the WPCs during the immersion for 2hr and 24hr is displayed in the table (4-5). The thickness of swell by VPP and RPP during this test was 0.03 and 0.02 in 2hr, similarly 0.042 and 0.036 for 24 hr. The thickness of swell for VPP matrix based composite varies from 0.43 to 4 for 2hr test and for 24hr test it varies from 1.05 to 7.50 whereas RPP it varies from 0.27 to 3.55 for 2 hr and for 24hr test it varies from 0.16-5.24 depending on the composite formulations. Thicknesses of swell shows commensurable to water absorption of the WPCs due to poor inter molecular linking between the wood flour and polymer matrix. The TS shows that with increase in wood flour content it goes on increasing similar to water absorption in both the VPP and RPP composite.

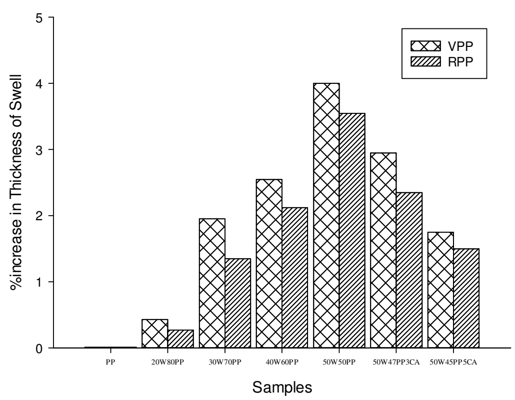


Figure- 4 Thickness of Swell 2hr

Specimen Code	Thickness of swell 2hr
VPP	0.01
RPP	0.01
VPP80W20	0.43
VPP70W30	1.95
VPP60W40	2.55
VPP50W50	4
RPP80W20	0.27
RPP70W30	1.35
RPP60W40	2.12
RPP50W50	3.55
50W47VPP3CA	2.95
50W47RPP3CA	1.75
50W45VPP5CA	2.35
50W45RPP5CA	1.5

Table- 4 Thickness of Swell 2hr

But for same wood content RPP shows less TS than VPP due to the fundamental segment that penetration the water mostly in lumens, the cell wall, and the voids at the intermolecular linking between wood dust and plastic matrix. Although, 3-5 w% MAPP coupled WPCs display less TS than WPCs without coupling agent. TS for 3% addition of MAPP coupled RPP and VPP WPCs reduce from 3.55-1.75 and 4-2.95 for 2 hr analysis. Identically, for 24hr test 5.24-3.74 and 7.50-4.8 respectively. TS for 5% addition of MAPP in RPP and VPP it reduces from 3.55-1.5 and 4-2.35 for 2hr analysis and 5.24-2.95 and 7.50-4.22 for 24hr analysis respectively. The MAPP increase this intermolecular linking between the two thus reduces the TS and water uptake at same wood content for 3w% and 5w%.

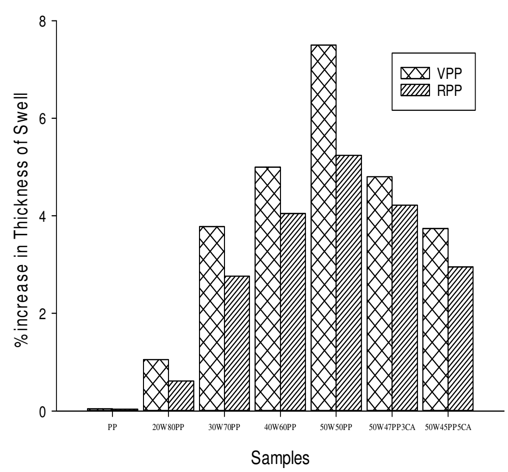


Figure- 5 Thickness of Swell 24hr

Specimen Code	Thickness of swell 24hr
VPP	0.042
RPP	0.036
VPP80W20	1.05
VPP70W30	3.78
VPP60W40	5.00
VPP50W50	7.50
RPP80W20	0.61

RPP70W30	2.76
RPP60W40	4.05
RPP50W50	5.24
50W47VPP3CA	4.8
50W47RPP3CA	3.74
50W45VPP5CA	4.22
50W45RPP5CA	2.95

Table-5 Thickness of Swell 24hr

(iii)Melt Flow Index

Melt flow index of the different formulation of PP (virgin and recycled) are given in table 6. The MFI of RPP (11.04) is lower than VPP (12.51), so this shows that due to reprocessing of the polymer there is in the decrease relative molecular mass and reduction in the relative molecular mass dispersion. The MFI of RPP composite material varies from 9.43 to 4.86 and VPP varies from 10.40 to 5.34. The VPP60W40 (6.54) compound and VPP50W50 (5.34) compound shows the decrease in the MFI of the compound due to the increase the internal friction between the wood and plastic molecules.

Specimen Code	MFI ratio
VPP	12.51
RPP	11.04
VPP80W20	10.40
VPP70W30	8.65
VPP60W40	6.54
VPP50W50	5.34
RPP80W20	9.43
RPP70W30	7.39
RPP60W40	5.57
RPP50W50	4.86

Table-6 Melt flow Index VPP and RPP

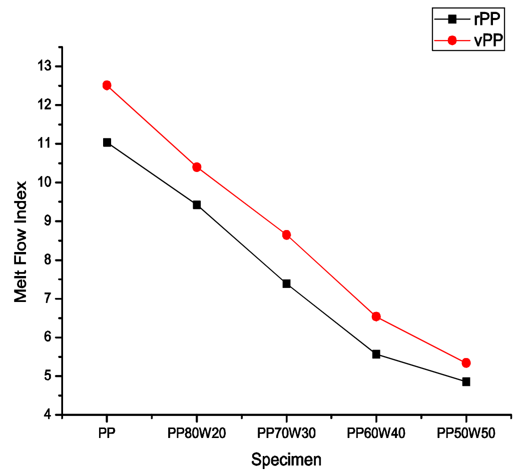
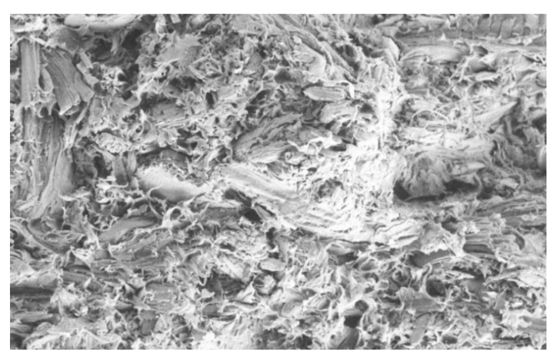


Figure 6: Melt flow index of VPP and RPP

This friction is due to increase in the wood content result in the increase of both dilatant and elongation viscosity. The VPP50W50(5.34) compound and RPP50W50(4.86) compound shows that the reprocessing develops the inter-linkage which results in molecular chain enlargement of plastic the flexibility of particle which led to the increase in viscosity thus reduces the MFI.

(iv)Microstructure Analysis

The microstructure of the tensile-fracture surface of tested samples is examined using SEM. The SEM images of WPCs are displayed in Figs. 7 and 8 respectively, in 500× magnification.



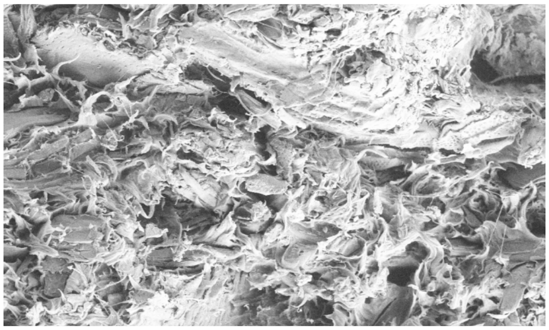
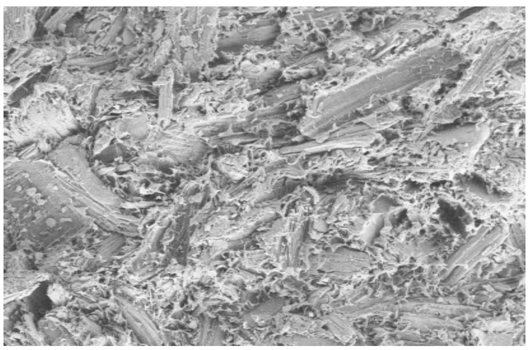


Figure:7 SEM images (×500) of fractured surface of (a) 50W50RPP, (b) 50W50VPP



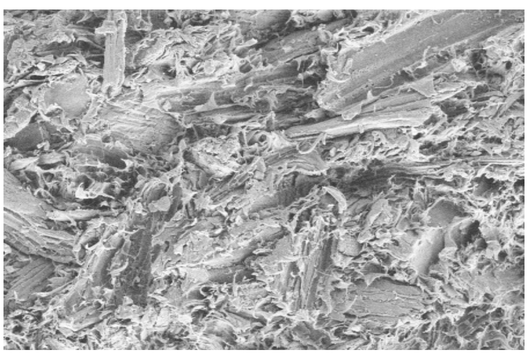


Figure:8 SEM images (×500) of fractured surface of (a) 50W47RPP3CA, (b) 50W45RPP5CA

The images confirms that facture of tensile specimen take place from surface with a poor inter molecular linking between the wood-wood particles and polymer matrix. This is due to the presence of voids and cluster between the wood and PP matrix. The fracture surface scan shows that the wood flour surfaces with observable trachaids and lumen, indicating the path of weaker part of the WPCs. The image shows that there is poor dissemination and rapport between the wood and PP matrix. The scan shows that there is homogeneous distribution of wood dust in recycled WPCs than virgin WPCs in Fig 7. With increase in wood content in WPCs there inproper distribution of polymer matrix .However, the tensile-fracture surface scan of 5wt% MAPP (Fig. 8b) showed extra brittleness than those of WPC having 3 wt% MAPP (Fig. 8a) . This improves the intermolecular linkage to a large extent. It was also seen in scan that composite with MAPP was irregular surface and without MAPP was regular surface.

V. CONCLUSION

During the analysis it has been observed that the WPCs are extremely affected by the filler materials. SEM images of tensile fracture confirms that an incorporation of MAPP increase the interlinking between the polymer and wood particles. Microstructure images of tensile fracture also clarify RPP matrix based WPCs has homogenous distribution of the wood filler than VPP based WPCs. Water uptake of RPP composite is lower than that of VPP composite due to increase in density of polymer because of recycling at the same wood content . Thickness swelling of WPCs follow similar trend of water absorption. Thickness swells in the formulations increase by the increase wood particles. The thickness swelling of RPP composite is low than VPP matrix based composite. It was found that my adding 3 to 5 W% MAPP reduces the water uptake and thickness of swell due to improvement in intermolecular linkage between the two .MFI decreases with increases in the wood particle in the composite due to extension of continuous chain of molecular reduce the flexibility of molecules in the polymer and increases viscosity.

VI. ACKNOWLEDGEMENT

I would like to express my gratitude and heart full thanks to Rajeev Srivastava, Associate Professor, MNNIT, Allahabad and L.P Singh, Assistant Professor, SHUATS, Allahabad for his valuable guidance and constant encouragement at various stages.

VII. REFERENCES

1. *Avila AF. Modeling Recycled Polymeric Matrix Composites: A Social Environmental Solution. Polym.-Plast. Technol. Eng. 2001; 40(4): 407–421.*
2. *CPCB Bulletin VOL-1 July 2016.*
3. *Gourmelon G. Global Plastic Production Rises, Recycling Lags. World watch Institute. 2015.*
4. *Sema A, Ervin T and Nami KS. Evaluation of relationship between moisture content and biological degradation of wood plastic composite. International Caucasian forestry symposium 2010;888-891*
5. *Falk RH, Mckeever DB. Recovering wood for reuse and recycling a United States perspective. In: Gallis DCT, editor. European COST E31 conference management of recovered wood recycling bio energy and other options. Thessaloniki: University Studio Press; 2004. p. 29–39.*
6. *Scott G. Green polymers. Polym Degrad Stab2000;68:1–7*
7. *Behzad Kord, The Impact of Plastics Virginity on Water Absorption and Thickness Swelling of Wood Plastic Composites, World Applied Sciences Journal, Vol.17, No.2, 2012, pp.168-171.*
8. *An Analysis of plastic consumption and recovery in Europe. Association of plastic manufacturer Europe: 2014-15.*
9. *Stark NM and Mautana LM. Surface chemistry and mechanical property change of wood flour /high density polyethylene composite after accelerated weathering. J. Appl. Polym Sci 2004; 96(6):2263-73.*
10. *A.K. Bledzki, M. Letman, A. Viksne, L. Rence, A comparison of compounding processes and wood type for wood fibre—PP composites‖, Elsevier Journal on Composites: Part A- Applied Science and Manufacturing, Vol.36, 2005, pp. 789–797.*
11. *La Mantia FP and Morreale M. Green composites: A brief review. J. Composite Part A: Applied Science and Manufacturing 2011;42:579–588.*
12. *Klyosov,Anole. A Wood Plastic composite 2007.*
13. *A.K. Bledzki, M. Letman, A. Viksne, L. Rence, A comparison of compounding processes and wood type for wood fibre PP composites, Elsevier Journal on Composites: Part A- Applied Science and Manufacturing, Vol.36, 2005, pp. 789–797.*
14. *Sebastien Migneault, Ahmed Koubaa, Fouad Erchiqui, Abdelkader Chaala, Karl Englund, Michael P. Wolcott, Effects of processing method and fiber size on the structure and properties of wood–plastic composites‖, Elsevier Journal on Composites: Part A- Applied Science and Manufacturing, Vol.40, October 2008, pp. 80–85*
15. *Sandeep Tamrakar and Roberto A. Lopez-Anido, Water absorption of wood polypropylene composite sheet piles and its influence on mechanical properties‖, Elsevier Journal on Construction and Building Materials, Vol.25, 2011,pp. 3977-3988.*
16. *Majid Tabkhpaz Sarabi, Amir Hossein Behravesh, Peyman Shahi and Yasser DaryabariEffect of polymeric matrix melt flow index in reprocessing extruded wood–plastic composites Journal of Thermoplastic Composite Materials 2014, Vol. 27(7) 881–894*
17. *J. Bhaskar, S. Haq, A.K.Pandey, N. Srivastava,―Evaluation of properties of propylene-pine wood Plastic composite‖, Journal of Material and Environmental Science, Vol.3, No.3, 2012, pp. 605-612.*
18. *Haq S and Srivastava R Investigations of wood thermoplastic composites for sustainable product applications. Discovery 2015; 39(176): 8-14.*
19. *American Society for Testing and Material Standard for ASTM standard D1238-12.*
20. *ASTM D570-98: Standard test method for water absorption of plastics: Annual book of ASTM Standards, West Conshohocken, PA, 2002.*