FORM- F

COUNCIL OF SCIENTIFIC AND INDUSTRIAL RESEARCH

Human Resource Development Group

(Extra Mural Research Division)

CSIR Complex, Library Avenue, Pusa, New Delhi 110012

PROFORMA FOR PREPARING FINAL TECHNICAL REPORT

(Ten copies of the report much be submitted immediately after completion of the research scheme)

1. Title of the scheme

Development of nanocomposite Materials From Waste Plastics and Non Conventional plant materials available in the forests of Assam.	Scheme No.: 01/(2287)/08/EMR-II Date of Commencement : 1-12-08 dd/mm/yy Date of termination : 30.11.2011 dd/mm/yy

2. Name and address of Principal Investigator

Prof. Tarun Kumar Maji
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Napaam, Assam-784028

3. Name of sponsoring laboratory of CSIR (if applicable)

Not applicable

4. Total grant sanctioned and expenditure during the entire tenure

	Amount Sanctioned	Expenditure
Staff	Nil	Nil
Contingency	304840.00/-	304840.00/-
Equipment	Nil	Nil
Total	304840.00/-	304840.00/-

5. Equipment(s) purchased out of CSIR grant

Name	Cost
Not applicable	Not applicable
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6. Research fellows associated with scheme

Name & Designation	Date of joining	Date of leaving
Not applicable	Not applicable	Not applicable
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7. Name(s) of the fellow(s) who received Ph.D. by working in the scheme, along with the title(s) of thesis: **Not applicable.**

8. List of research papers published/communicated, based on the research work done under the scheme (Name(s) of author(s), Title, Journal, Volume number, Year and pages should be given for each paper published and a copy of each of them should be enclosed; reprints/copies of papers appearing after submission of FTR should also be sent to CSIR):

   - Effect of coupling agent and nanoclay on properties of HDPE, LDPE, PP, PVC blend and *Phargamites karka* nanocomposite. *B. K. Deka & **T. K. Maji***, Compos. Sci. Technol. 2010;70(12):1755-1761.
   - Study on the properties of nanocomposite based on high density polyethylene, polypropylene, polyvinyl chloride and wood. *B. K. Deka & **T. K. Maji***, Composites: Part A 2011;42(6):686-693.
   - Study on properties of nanocomposites based on HDPE, LDPE, PP, PVC, wood and clay. *B. K. Deka, **T. K. Maji** & M. Mandal* Polym. Bull. 2011; 67(9):1875–1892
   - Effect of different compatibilizer and nanoclay on physical properties of wood (*Phragmites karka*) polymer composite. *B. K. Deka, N. Dutta & **T. K. Maji***, Polym. Renew. Resour. 2011;2(3):87-103.
   - Effect of Nanoclay and ZnO on the Physical and Chemical Properties of Wood Polymer Nanocomposite. *B. K. Deka & **T. K. Maji***, J. Appl. Polym. Sci. (2011) DOI 10.1002/app. 35314.
   - Effect of TiO_2 and nanoclay on the properties of wood polymer nanocomposite. *B. K. Deka & **T. K. Maji***, Composites: Part A 2011;42(12):2117-2125.
   - Effect of silica nanopowder on the properties of wood flour/polymer composite, *B. K. Deka & **T. K. Maji***, Polym. Eng. Sci. 2011 (accepted).

9. Details of new apparatus or equipment designed or constructed during the investigation: **Not applicable.**

10. The likely impact of the completed work on the scientific/technological potential in the country (this may be attached as Enclosure-I): **Attached as Enclosure-I.**

11. Is the research work done of some industrial or agricultural importance and whether patent(s) should be taken? Yes/No; if yes, what action has been/should be taken: **No.**

12. How has the research work complemented the work of CSIR Laboratory that sponsored your scheme? : **Not applicable.**

13. Detailed account of the work carried out in terms of the objective(s) of the project and how far they have been achieved; results and discussion should be presented in the manner of a scientific paper/project report in about 5000 words; and this should be submitted as enclosure-II to this report : **Attached as Enclosure-II.**

14. An abstract of research achievements in about 200-500 words, suitable for publication.

Wood polymer composite (WPC) was developed by using solution blended high density polyethylene (HDPE), low density polyethylene (LDPE), polypropylene (PP), poly(vinyl chloride) (1:1:1:0.5) and wood flour prepared from Nal (*Phragmities karka*), a type of non conventional plant materials. The ratio of solvents xylene and tetrahydrofuran used for the blending process was optimized as 70:30. The miscibility among the polymers and with wood flour was studied by using compatibilizer viz. glycidyl methacrylate (GMA), polyethylene-*co*-glycidyl methacrylate (PE-*co*-GMA) and polyethylene-*graft*-maleic anhydride (PE-*g*-MA). Polyethylene-*co*-glycidyl methacrylate was the most efficient compatibilizer among the studied three compatibilizers. The properties of the composite were improved by the use of clay. WPC developed with organically modified clay showed superior properties compared to the composite developed with unmodified clay. Maximum improvement in properties was obtained by the addition of 3 phr clay. At higher percentage of clay (5 phr), the properties of the composite decreased due to agglomeration of clay. The mechanical properties of the composite were further enhanced by using SiO_2 nanoparticles in combination with clay. The incorporation of SiO_2 along with clay (3 phr each) improved thermal, flame retardancy, mechanical and water resistance properties. TiO_2 nanoparticles in combination with clay were also used in some of the composites to improve UV resistance. Maximum improvement in UV stability and thermal stability were achieved by the addition of 3 phr each of clay and TiO_2 .The addition of ZnO nanoparticles with clay further enhanced the thermal, UV resistance and flame retardancy. The addition of 3 phr each of clay and ZnO to the composite improved UV resistance, thermal resistance, flame retardant property etc. At 3 phr clay and 5 phr ZnO loading, the occurrence of surface interaction among the nanoparticles resulted in the decrease of properties. The addition of nanofillers like clay, TiO_2, SiO_2 and ZnO either alone or in combination into wood /polymer composite were found to improve the various properties like mechanical, thermal, UV resistance, hardness etc.

15. Mention here whether or not the unspent grant has been refunded to CSIR: Does not arise.

Date: 28-12-11

Tarun K Maji
Signature of PI

MAJI

Sciences
ity

Note: Final Technical Report is expected to be self-contained complete report of the work done. Please do not leave any column unanswered.

Enclosure-I

Impact of the completed work on the scientific/technological potential in the country

Amongst the different types of plastics, high density polyethylene (HDPE), low density polyethylene (LDPE), polypropylene (PP) and polyvinyl chloride (PVC) are mostly used in industries. After use, the throwing of plastic materials here and there in the form of carry bags, boxes, packaging film causes a serious threat to the environment. Recycling and reusing is one of the processes to reduce this environmental pollution problem. One of the fundamental goals of recycling is to improve different properties of the recycled plastics. The properties can be improved substantially if composites are made by combining these waste materials with cellulosic materials.

Nal (*Phragmites karka*), a type of nonconventional plant is widely available not only in the forests of Assam but also on both the banks of The Brahmaputra river. These plants are not considered for structural applications due to their poor mechanical, dimensional and other properties. They are mostly used for making temporary shades and domestic fuels. These plants can be made value added products by producing composites with different polymers. Due to non availability of the melt mixer, the work was carried out by solution blending technique. But in order to choose solvent/solvents, the ratio of different plastics in the waste plastic material is essential. Due to that reason, virgin plastics of known composition were used. It is anticipated that knowledge generated from this study will provide some valuable information for the development of waste plastics/wood composite.

The treatment of wood with various nonomaterials significantly improved the mechanical properties, UV resistance, thermal stability, water resistance, biodegradability etc. The information emerged from the study may also help the wood industries to explore the possibilities of making hybrid constructions and this can also take the wood industries to a new direction.

Wood is biodegradable. Most of the alternative non wood materials such as concrete, steel etc. used for construction purposes are not biodegradable. In country like India, where there are a large number of environmental problems, this may be a contribution towards addressing at least are such issue. The wood/ polymer composite will not only reduce the environmental pollution problem but also will definitely boost the economy of this region.

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ANNEXURE-II

(Final Progress Report)

Part A: **Study on the properties of nanocomposite based on high density polyethylene, polypropylene, polyvinyl chloride, wood and clay.**

In this part of work, a mixture of high density polyethylene (HDPE), polypropylene (PP), polyvinyl chloride (PVC) and glycidyl methacrylate (GMA) were used as polymer matrix and compatibilizer respectively. The aim of this study was to prepare and evaluate the various properties of the nanocomposite. The nanocomposites were prepared by solution blending method using polymer matrix, GMA as stated, wood flour and organically modified MMT (CTAB-modified).

Montmorillonite (MMT) was modified by cetyl trimethyl ammonium bromide (CTAB) and verified by X-ray diffractometer. The interlayer spacing for modified clay was found to increase. The interlayer spacing was further increased in WPC reinforced with modified clay as studied by X-ray diffractometer.

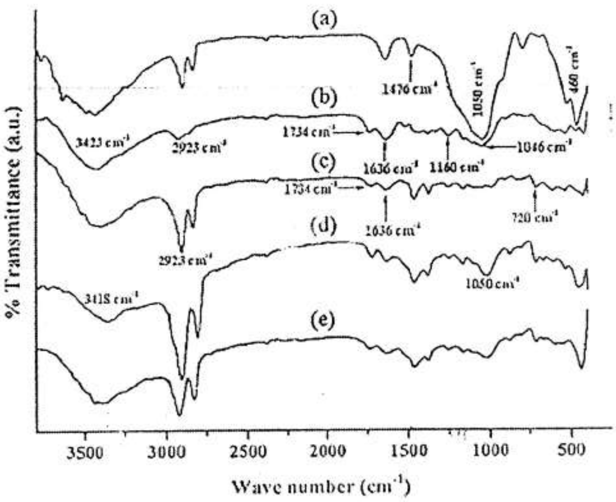

Figure 1. FTIR spectra of (a) modified MMT (b) wood (c) PB/G10/W40 (d) PB/G10/W40/C3 (e) PB/G10/W40/C3*.

FTIR study indicated an interaction between wood, GMA treated polymer blend and nanoclay. Glycidyl methacrylate (GMA) improved the compatibility among the polymers as revealed by SEM study. SEM study also showed more roughness on the surface of unmodified clay treated WPC compared to modified clay treated WPC. TEM study showed an increase in interlayer spacing in WPC treated with CTAB modified clay compared to WPC treated with unmodified clay. Significant improvements in mechanical properties, thermal properties and flammability were obtained in WPC treated with CTAB modified clay. Modified clay based WPC exhibited lower water absorption and highest hardness compared to WPC or unmodified clay treated WPC.

Table 1. Flexural, tensile and hardness properties of polymer blend and WPC loaded with unmodified and modified MMT.

Sample	Flexural properties		Tensile properties		Hardness
	Strength (MPa)	Modulus (MPa)	Strength (MPa)	Modulus (MPa)	(Shore D)
PB	13 (± 2)	742 (± 1)	5 (± 2)	84 (± 17)	65.6 (±1.0)
PB/G10	16 (± 2)	1084 (± 2)	9 (± 1)	172 (± 18)	68.8 (±0.5)
PB/G10/W40	18 (± 1)	3895 (± 1)	19 (± 1)	315 (± 17)	67.0 (±1.0)
PB/G10/W40/C3*	22 (± 2)	4254 (± 1)	25 (± 1)	444 (± 17)	72.5 (±0.7)
PB/G10/W40/C3	25 (± 1)	4682 (± 1)	30 (± 1)	513 (± 18)	76.2 (±0.6)

***Part B*: Effect of different compatibilizer and nanoclay on physical properties of wood (*Phragmites karka*) polymer composite.**

The present investigation has been carried out to study and compare the effect of different compatibilizer on the various properties of WPC prepared by using nonconventional plant materials and mixture of plastics. The effect of nanoclay alongwith the compatibilizer on the final properties of WPC has also been investigated.

WPC was prepared by using three different compatibilizers namely glycidyl methacrylate (GMA), polyethylene-*graft*-maleic anhydride (PE-*g*-MA) and polyethylene-*co*-glycidyl methacrylate (PE-*co*-GMA). It was observed that WPC having mixture of all the three compatibilizer showed maximum improvement in miscibility compared to WPC containing glycidyl methacrylate, polyethylene-*graft*-maleic anhydride and polyethylene-*co*-glycidyl methacrylate alone as compatibilizer. The miscibility was judged by the appearance of smoothness of the fractured surface. FTIR study showed that the shifting and reduction in intensity of the hydroxyl group were more in PE-*co*-GMA and PE-*g*-MA compatibilized WPC compared to GMA compatibilized WPC. The shifting was further decreased in WPC compatibilized with (1:1:1) molar ratio of blended compatibilizer and nanoclay. WPC reinforced with nanoclay and compatibilized with (1:1:1) molar ratio of GMA, PE-*g*-MA and

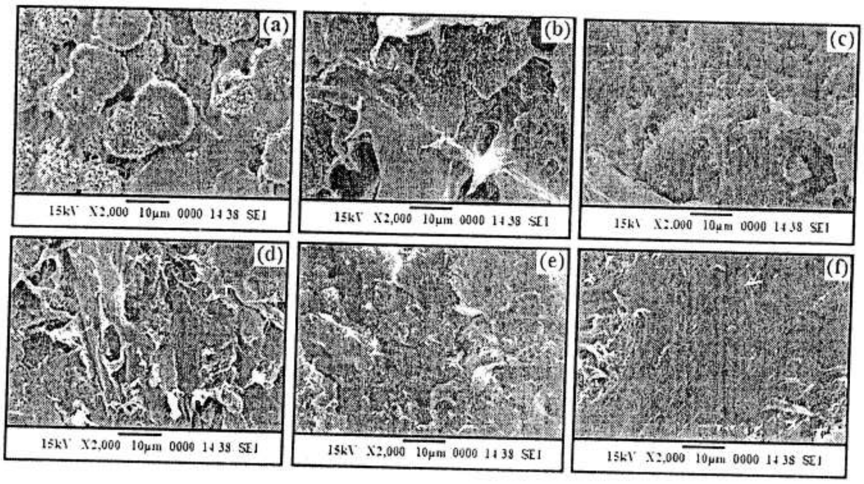

Figure 2. SEM micrographs of (a) PB (b) PB/G7/W40 (c) PB/PM7/W40 (d) PB/PG7/W40 (e) PB/(G+PM+PG)7/W40 and (f) PB/(G+PM+PG)7/W40/N3.

PE-*co*-GMA showed maximum improvement in tensile, flexural and hardness properties. Thermal stabilities of the WPC enhanced over virgin wood due to incorporation of compatibilizer. Maximum thermal stability and flame resistance property were noticed for nanoclay based WPC compatibilized with (GMA+PE-*g*-MA+PE-*co*-GMA) followed by WPC compatibilized with PE-*co*-GMA, PE-g-MA and GMA. Nanoclay reinforced mixed compatibilizer based WPC showed least water absorption in comparison with polymer blend and other compatibilizer based WPC.

***Part C*: Effect of coupling agent and nanoclay on properties of HDPE, LDPE, PP, PVC blend and *Phragmites karka* nanocomposite.**

The objective of the present study was to prepare the nanocomposites using wood flour, PE-*co*-GMA compatibilizer, nanoclay and polymer mixture of (HDPE + LDPE + PP + PVC) by solution blending. Efforts have also been made to study the various properties like mechanical, thermal, flame retardancy, water resistance, biodegradation etc. of the nanocomposite.

The distribution of silicate layers of nanoclay in wood polymer matrix was investigated by XRD and TEM studies. X-ray diffraction studies of WPC treated with 1 and 3 phr nanoclay showed higher exfoliation compared to WPC treated with 5 phr nanoclay. TEM study also supported the above findings. FTIR studies indicated an interaction between wood, PE-*co*-GMA treated polymer blend and clay. It was found that the intensity of the hydroxyl peak decreased as well as shifted to lower wave number in the wood polymer composite.

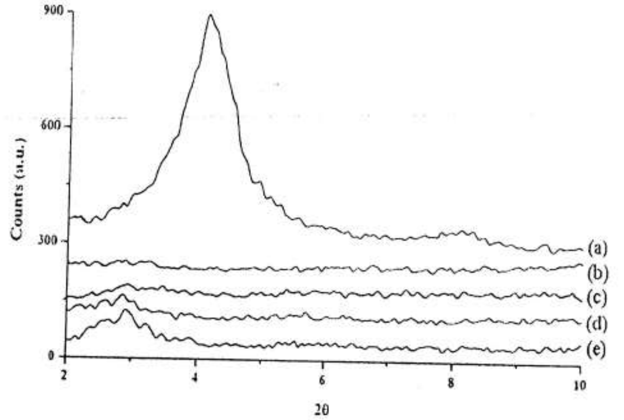

Figure 3. X-ray diffraction of (a) nanomer (b) PB/G5/W40/N1 (c) PB/G5/W40/N3 (d) PB/G5/W40/N5 (e) PB/G5/N3.

Furthermore, the intensity of peaks corresponding to –CH stretching was more in wood composites compared to pure wood which indicated the formation of bond between polymers, PE-*co*-GMA and wood. The increase in miscibility among polymers due to addition of PE-*co*-GMA as compatibilizer was studied by SEM study. In WPC, there was no significant difference in the surface characteristics on increasing the amount of nanomer from 1.0 to 3.0 phr. However, the surface appeared little bit rough on addition of 5 phr of clay. It was observed that both flexural and tensile properties of polymer blends increased on addition of PE-*co*-GMA and wood flour. The incorporation of nanoclay with wood, polymer blend and PE-*co*-GMA further enhanced the flexural and tensile properties. Both flexural and tensile values increased with clay loading up to 3 phr, beyond that the values decreased. Hardness values also increased as PE-*co*-GMA and clay was added to the polymer blend. The storage and loss modulus were found to enhance on incorporation of clay to WPC. The damping peak was found to be lowered by the addition of clay to WPC. T_i and T_m value of polymer blend improved on addition of PE-*co*-GMA and wood flour. The values were found to enhance further when nanomer was added. The values increased upto addition of 3 phr clay beyond that it decreased. Nanomer showed highest RW values while the polymer blend showed lowest RW values. The trend of RW values of clay treated WPC was similar to those of T_i values. Further, it was observed that polymer blend decomposed at higher temperature compared to wood flour. Temperature of decomposition (T_D) values increased on addition of wood flour and PE-*co*-GMA to the polymer blend. T_D value increased initially upto addition of 3 phr clay after that it decreased with the increase in the amount of clay (5 phr). The LOI values of the nanoclay treated wood polymer composites were found more compared to nanoclay untreated wood polymer composite. The higher the percentage of nanoclay, the higher was the LOI.

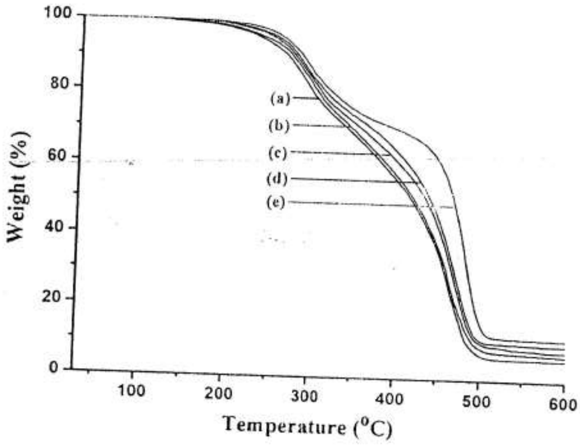

Figure 4. Themogravimetric curves of (a) PB, (b) PB/G5/W40, (c) PB/G5/W40/N1, (d) PB/G5/W40/N5 and (e) PB/G5/W40/N3.

Composites samples were exposed for microbial degradation for eight weeks and wood polymer composites had shown high rate of degradation. It was observed that with increasing bacterial exposure time, the growth of bacterial stains increased. With the increase in the clay content, the rate of bacterial growth enhanced. From the study, it was observed that WPC loaded with 5 phr clay showed maximum bacterial growth. It was found that with efficient degradation of WPCs, flexural and tensile properties of the WPCs decreased. In all the cases, the water uptake was found to increase with the increase of time of immersion. The water absorption of the neat polymer decreased on addition of PE-*co*-GMA. It decreased further on addition of nanomer to the PE-*co*-GMA treated polymer blend. The water absorption was found to enhance when wood flour was added. The water absorption of wood flour/polymer blend composite decreased with the incorporation the clay. The higher the amount of clay, the lower was the water absorption.

Part D: **Effect of Nanoclay and SiO_2 on the Properties of Wood Polymer Nanocomposite.**

Mechanical property improvement is an important parameter in wood polymer composite. Most of the fillers are used to improve some particular property of composite. In polymer composite, SiO_2 nanopowder is one of the widely used filler. SiO_2 can enhance the mechanical as well as thermal properties of the composite. In this part, we report the modification of SiO_2 by treatment with cetyl trimethyl ammonium bromide and study the effect of modified SiO_2 nanopowder alongwith nanoclay on various properties of composites based on wood, PE-*co*-GMA and polymer mixture of HDPE, LDPE, PP and PVC.

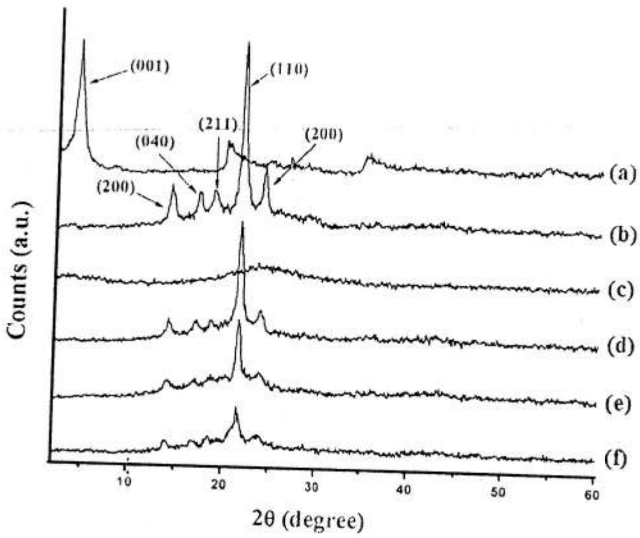

Figure 5. X-ray diffraction of (a) Nanoclay (b) PB (c) nano SiO_2 (d) PB/G5/W40/N3/S1 (e) PB/G5/W40/N3/S3 (f) PB/G5/W40/N3/S5.

The distribution of silicate layers of nanoclay and SiO_2 in the composite was examined by XRD and TEM study. The improvement in compatibility among the polymers and WF by using polyethylene-*co*-glycidyl methacrylate (PE-*co*-GMA) as compatibilizer was improved as studied by SEM. Surface modification of SiO_2 nanoparticles by cationic surfactant CTAB and the interactions among wood, PE-*co*-GMA, SiO_2 and nanoclay were examined by FTIR study. WPC loaded with nanoclay and SiO_2 showed a remarkable improvement in mechanical properties. Thermal and flame retardance properties were also increased in nanoclay/SiO_2 loaded WPC. Water uptake of composite decreased after the incorporation of nanoclay and SiO_2 nanoparticles. WPC loaded with 3 phr each of clay and SiO_2 exhibited maximum improvement in properties.

Part E: **Effect of Nanoclay and TiO_2 on the Properties of Wood Polymer Nanocomposite.**

Among many nanocomposite precursors, TiO_2 nanopowder is increasingly being investigated because it is non-toxic, chemically inert, low cost, corrosion resistant and has a high refractive index, UV filtration capacity and high hardness. In the present study, wood polymer nanocomposite has been prepared by using polymer blend (HDPE, LDPE, PP, PVC), wood flour, PE-co-GMA and clay/TiO_2 combined nanopowder. Effect of inclusion of clay/TiO_2 on different properties of the composite has also been highlighted in the present study.

Surface modification of TiO_2 by cationic surfactant CTAB was done and confirmed by FTIR study. The exfoliation of silicate layers in the wood polymer matrix and appearance of crystalline peak of TiO_2 was examined by X-ray diffraction study. TEM study revealed the distribution of nanoclay and TiO_2 nanoparticles in the wood polymer matrix. The compatibilizer improved the miscibility by enhancing the interfacial adhesion among the polymers. The smoothness of fractured surface of composites was improved due to the incorporation of wood, clay and TiO_2 into the composites as observed by SEM study. At constant clay loading (3 phr), the fractured surface of WPC loaded with 5 phr TiO_2 appeared less smoother compared to WPC loaded with 3 phr TiO_2. Strong interaction between polymer blend, wood, nanoclay and organically modified TiO_2 was confirmed by FTIR study. The shifting of hydroxyl peak to lower wave number and increase in $-CH_2$ peak intensity were observed maximum in the case of WPC loaded with 3 phr each of clay and TiO_2.

The mechanical properties were found to increase after the incorporation of clay and TiO_2. Flexural, tensile and hardness were found maximum in WPC loaded with 3 phr clay and TiO_2. WPC loaded with nanoclay and TiO_2 showed an improvement in thermal properties. UV stability of the composite was found to increase by incorporation of TiO_2. After 60 days of exposure to UV irradiation, WPC loaded with 3 phr TiO_2 showed lowest weight loss. The incorporation of TiO_2 improved the UV resistance as evident from carbonyl index measurement and SEM study. Nanoclay/TiO_2 treated WPC further improved the flame retardancy and decreased the water absorption capacity.

Table 2. Flexural, tensile and Hardness properties of polymer blend and WPC loaded with different percentage of nanoclay and TiO_2.

Sample	Flexural properties		Tensile properties		Hardness
	Strength (MPa)	Modulus (MPa)	Strength (MPa)	Modulus (MPa)	(Shore D)
PB	12.78 ± 0.35	755.68 ± 1.12	6.06 ± 1.02	85.92 ± 17.72	67.4 (± 0.6)
PB/G5	15.51 ± 1.01	1014.21 ± 1.09	9.05 ± 1.31	116.24 ± 16.91	68.0 (± 0.5)
PB/G5/W40	16.86 ± 1.10	3770.91 ± 1.14	17.14 ± 1.09	260.81 ± 17.39	66.7 (± 0.3)
PB/G5/W40/N3/T1	28.62 ± 0.81	4842.81 ± 1.08	33.52 ± 1.37	596.12 ± 18.27	77.4 (± 0.3)
PB/G5/W40/N3/T3	33.85 ± 1.06	5072.64 ± 1.25	36.03 ± 1.15	653.86 ± 17.14	80.9 (± 0.5)
PB/G5/W40/N3/T5	30.38 ± 1.13	4903.90 ± 1.72	34.72 ± 1.18	620.57 ± 17.53	78.1 (± 0.3)

***Part F*: Effect of Nanoclay and ZnO on the Physical and Chemical Properties of Wood Polymer Nanocomposite.**

Thermal stability is one of the important properties of wood polymer composite (WPC). It has been established that thermostability along with the other properties of the composite can be improved by using clay particles. The present study is aimed to discuss the effect of ZnO nanopowder along with nanoclay to the thermal and mechanical properties of HDPE/LDPE/PP/PVC blend/wood composite. The aim is also to study the effect of ZnO to other properties like UV resistance, flame retardancy and water uptake of the composites.

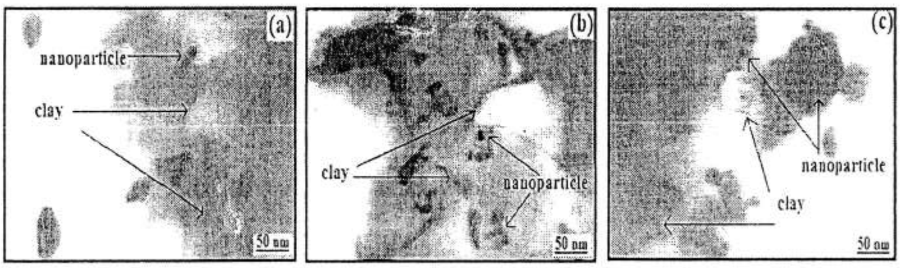

Figure 6. TEM micrographs of (a) PB/G5/W40/N3/Z1 (b) PB/G5/W40/N3/Z3 (c) PB/G5/W40/N3/Z5.

The distribution of silicate layers of nanoclay and ZnO in WPCs were examined by XRD and TEM study. The compatibility among the polymers and wood flour was improved by using polyethylene-*co*-glycidyl methacrylate (PE-*co*-GMA) compatibilizer as revealed by SEM study. The fractured surface of composite having 3 phr each of nanoclay and ZnO appeared to be smoother compared to those of composite prepared with either 1 or 5 phr ZnO and 3 phr nanoclay. Surface modification of ZnO nanoparticles by cationic surfactant cetyl trimethyl ammonium bromide (CTAB) was examined by FTIR studies. The interactions among wood, PE-*co*-GMA, ZnO and nanoclay were studied by FTIR. Both flexural and tensile properties of the polymer blend increased after incorporation of compatibilizer and wood flour. At a fixed clay loading (3 phr), both the flexural and tensile properties improved upto addition of 3 phr of ZnO. The properties decreased on addition of higher amount of ZnO (5 phr). Hardness value was found maximum at 3 phr clay/ZnO loading, after that it decreased. WPC treated with clay and ZnO showed an improvement in thermal stability.

Table 3. Thermal analysis of polymer blend and wood polymer nanocomposite loaded with clay and different percentage of ZnO.

Sample	T_i	$T_m{}^a$	$T_m{}^b$	Temperature of decomposition (T_D) in °C at different weight loss (%)				RW% at 600°C	LOI (%)
				20%	40%	60%	80%		
PB	249	270	407	291	388	439	468	6.1	20
PB/G5/W40	255	276	451	299	397	446	473	7.2	38
PB/G5/W40/N3/Z1	277	326	503	330	459	484	501	10.8	53
PB/G5/W40/N3/Z3	289	337	517	350	478	497	513	14.5	68
PB/G5/W40/N3/Z5	281	330	510	336	465	490	508	12.7	66

T_i: value for initial degradation; ^aT_m: value for 1st step; ^bT_m: value for 2nd step.

Both initial decomposition temperature (T_i) and maximum pyrolysis temperature (T_m) value were found maximum when the concentration of ZnO was 3 phr. At that concentration, RW value was also found maximum. The incorporation of ZnO improved the UV resistance of the composites as judged from the weight loss, carbonyl index value and SEM study. Nanoclay/ZnO treated WPC further improved the flame retardancy and decreased the water absorption capacity.

Section G: **Synergistic effect of SiO_2, ZnO and Nanoclay on the Physical and Chemical Properties of Wood Polymer Nanocomposite.**

The present study was aimed to discuss the effect of SiO_2 and ZnO nanopowder along with nanoclay to the thermal and mechanical properties of HDPE/LDPE/PP/PVC blend/wood composite The aim was also to study the effect of nanoclay, SiO_2 and ZnO to other physical properties like water uptake, hardness and flame retardancy of the composites.

The distribution of silicate layers of nanoclay and SiO_2/ZnO in WPCs was examined by XRD and TEM study. The compatibility among the polymers and WF was improved by using PE-*co*-GMA compatibilizer as revealed by SEM study. Surface modification of SiO_2 and ZnO nanoparticles was done by cationic surfactant CTAB and examined by FTIR studies. It was observed that WPC loaded with 3 phr each of nanoclay, SiO_2 and ZnO exhibited maximum improvement in compatibility. At higher concentration of SiO_2 and ZnO loading, the particles became agglomerated.. The interactions among wood, PE-*co*-GMA, SiO_2, ZnO and nanoclay were also studied by FTIR. The shifting and decrease of intensity of peak corresponding to –OH stretching to lower wave number confirmed the reaction between polymer, wood, SiO_2, ZnO and nanoclay.

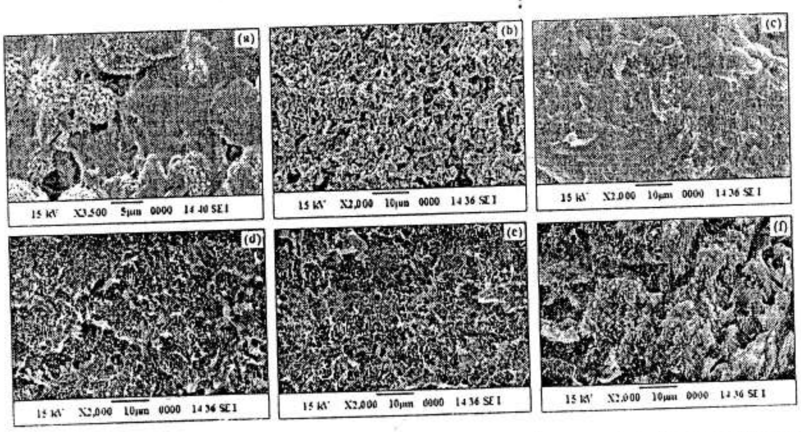

Figure 7. SEM micrographs of (a)PB(b)PB/G5 (c)PB/G5/W40 (d)PB/G5/W40/N3/S1/Z1 (e) PB/G5/W40/N3/S3/Z3 and (f) PB/G5/W40/N3/S5/Z5.

After incorporation of compatibilizer, both flexural and tensile properties of the polymer blend increased due to increase in interfacial adhesion between the polymers. The flexural and tensile properties of the composite were improved further after the addition of

WF. WF acted as a load carrier, reinforced the composites and increased the flexural and tensile properties. The properties of the WPCs were further improved after the incorporation of clay, SiO_2 and ZnO nanopowder. At a fixed clay loading (3 phr), both flexural and tensile properties improved upto addition of 3 phr each of SiO_2 and ZnO. At higher amount of SiO_2 and ZnO (5 phr) loading, the properties were found to be decreased. The observed higher values might be due to the combined effect of nanoclay, SiO_2 and ZnO. The silicate layers of nanoclay acted as a reinforcing agent and restricted the mobility of the long polymer chains inserted inside its gallery space.

Table 4. Flexural and tensile properties of polymer blend and WPC loaded with nanoclay and different percentage of SiO_2 and ZnO.

Sample	Flexural properties		Tensile properties		Hardness (Shore D)
	Strength (MPa)	Modulus (MPa)	Strength (MPa)	Modulus (MPa)	
PB	13.97 ± 1.01	762.72 ± 1.03	6.35 ± 1.21	93.51 ± 17.49	66.3(± 0.6)
PB/G5	17.31 ± 0.85	1052.76 ± 1.07	9.87 ± 1.29	125.54 ± 16.71	67.9(± 0.4)
PB/G5/W40	20.14 ± 1.02	3887.63 ± 1.06	20.02 ± 1.31	267.15 ± 17.64	67.2(± 0.5)
PB/G5/W40/N3/S1/Z1	29.12 ± 1.63	4934.75 ± 1.19	34.37 ± 1.21	598.43 ± 16.62	78.4(± 0.7)
PB/G5/W40/N3/S3/Z3	34.19 ± 0.87	5184.27 ± 0.83	37.88 ± 1.07	684.32 ± 18.34	81.0(± 0.2)
PB/G5/W40/N3/S5/Z5	31.26 ± 1.14	5047.24 ± 1.11	35.36 ± 1.23	632.73 ± 20.63	79.1(± 0.2)

WPC loaded with nanoclay, SiO_2 and ZnO enhanced other properties like hardness, thermal, UV resistance, chemical resistance and reduced the water absorption capacity. WPC loaded with 3 phr each of clay, SiO_2 and ZnO exhibited maximum improvement in properties.

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तेजपुर विश्वविद्यालय
(केंद्रीय विश्वविद्यालय)
नपाम, तेजपुर - 784 028, असम, भारत

TEZPUR UNIVERSITY
(A Central University)
Napaam, Tezpur - 784 028, Assam, India

UTILIZATION CERTIFICATE

This is to certify that expenditure claimed under different heads has actually been incurred and utilize properly during the period (01.12.2008 – 30.11.2011) and further that the grant has been exclusively utilized for the purpose for which it was sanctioned.

22/12/11
Signature of Finance Officer

(With stamp)

22/12/11
Internal Audit Officer
Tezpur University

Signature of PI

(With stamp)

TARUN K MAJI
Professor
Dept. of Chemical Sciences
Tezpur University

फोन / Phone : 03712-267007 - 9 (3 lines) • फेक्स / Fax : 03712-267005, 267006 • ई-मेल / e-mail : admn@tezu.ernet.in

ANNEXURE –II

Consolidated Statement of Account:
From the date of commencement : **01.12.2008 till 30.11.2011**
Scheme Number : **01 (2287)/08/EMR – II dated 20.11.08**
Title of the Research Scheme : **Development of Nanocomposite……………………………forest of Assam.**
Name of the Investigator-in-charge : **Prof. Tarun K. Maji**
Date of Commencement : **01.12.2008** Date of Termination: **30.11.2011**

Receipts (Particulars of grant received)								Payments (Particulars of grant spent)						
Period (ending 30 November)	Cheque No., Date & Amount	Stipend	Contingency	Scientist Allowance(for Emeritus Scientist Scheme only)	Equipment grant	HRA + MA	Total	Stipend	Contingency	Scientist Allowance(for Emeritus Scientist Scheme only)	Equipment grant	HRA + MA	Total	Balance
01.12.08 to 30.11.11	DD No. 380633 dt 7.01.09 for Rs 41,667/- DD No. 839675 dt 16.07.09 for Rs 69,173/- DD No. 300040 dt. 27.07.10 for Rs. 94,000/- DD No. 012468 dt 12.09.11 for Rs. 1,00,000/-	NIL	Rs. 41,667/- Rs. 69,173/- Rs. 94,000/- Rs. 1,00,000/-	NIL	NIL	NIL	Rs. 3,04,840/-	NIL	Rs. 41,667/- Rs. 69,173/- Rs. 94,000/- Rs. 1,00,000/- } Rs. 3,04,840/-	NIL	NIL	NIL	Rs. 3,04,840/-	NIL

Signature of Registrar 22|12|11
With Stamp

Signature of Finance Officer
With Stamp

Internal Audit Officer
Tezpur University

Signature of PI
With Stamp
TARUN K MAJI
Professor
Dept. of Chemical Sciences
Tezpur University