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Investigations on mechanical peculiarity of Nano Titanium Oxide filled vinyl ester based Functionally Graded Materials

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***Abstract*— Filler as reinforcing material plays a major role for the strength of composite materials. It is also depends on the fabrication methodology of the composite materials. The aim of this work is to find out the influence of nano Titanium Oxide (TiO_2) filler and fabrication technique on the mechanical properties of filler filled vinyl ester composites. TiO_2 filled vinyl ester based nano homogeneous composites (HNCs) and their functionally graded materials (FGMs) are fabricated using stirring and centrifugal casting technique, respectively. HNCs and FGMs are fabricated with the reinforcement of 5wt% and 10wt% of nano TiO_2 fillers respectively. Neat vinyl ester is also fabricated for the performance compression with HNC and FGMs. Result finding shows that nano TiO_2 filled FGMs performed better than HNCs. Mechanical properties neat vinyl ester is minimum among the all the fabricated composites.**

Index Terms—Nano TiO_2 filler, Vinyl ester resin, FGMs. Mechanical properties

1. INTRODUCTION

In the present scenario, polymer composites are frequently employed as sliding elements in various industrial applications. In practice, special fillers are important for these purposes to improve the relatively poor load carrying capacity of neat polymers. One of the major benefits of nanocomposites is that it required low concentration of fillers as compared to micro composites and performed better. However, it is agglomerate very easily into polymer because of high percentage of atoms on the surface of nanoparticles, which are not enough for getting a homogeneous dispersion state of nanoparticles [1].

Titanium Oxide is representing with the chemical formula of TiO_2. It is the compound of nitrogen and boron having the property of heat and chemically resistant refractory material. TiO_2 is generally exists in the crystalline forms. It is frequently used in cosmetic products because of their structure is the most stable and soft. Nano fillers reinforced composites have superior wear resistance and mechanical properties [3, 4]. The inclusion of fillers into polymers affects the cost and stiffness of the composites [5, 6]. Patnaik et al. [7] fabricated the silicon carbide filler filled epoxy matrix composite and examine the erosion wear performance of fabricated composites. They found that SiC filled composite performed better as compared to unfilled composite. It is also observed that mechanical properties of fabricated composites are enhanced. Pravurum et al. [8] investigate the parametrical effect on the aluminium nitride and flass fiber filled epoxy composites. Result finding shows that impact angle has significant effect on the erosion wear whereas temperature has minimum effect on the performance of fabricated composites.
N. Mohan et al. [9] use the vacuum assisted resin infusion (VARI) technique to fabricate the (WC) filled GF-epoxy composite. Remarkable improvement is observed in the toughness of fabricated composites with the incorporation of WC micro fillers. It is also observed that tensile strength and impact strength is also increase as compared to neat epoxy composite. The fracture energies of filler filled epoxy and polyester resin is examined by Karger et al. [10]. It has observed that crack growth increase initially for certain fraction of volume and then decreased. This phenomenon is observed for both matrix material based composites. FGMs come under the excellent class of materials group. Property of the FGMs is very from one end to other end of FGMs samples. Changes are occurred at the micro level in the FGMs. There are two types of FGMs. One is continuous graded FGMs and other is the step graded FGMs [11]. Various types of fillers have been used by investigators to manufacture FGMs [12-19]. Tribological behavior of ultra-high molecular weight polyethylene (UHMWPE) filled epoxy based FGM has been investigated by Chand et al. [20].

It has been observed from literature review that much work have been done on fillers filled vinyl ester based FGMs but from the author's observation, nano- TiO_2 filled vinyl ester based FGMs have not been developed so far. The focus of current work is to fabricate nano TiO_2 reinforced vinyl ester based HNC and FGMs and to examine their mechanical properties.

2. DETAILS OF THE EXPERIMENTAL WORK SAMPLE FABRICATION

Detailed information about HNC and their FGMs is given in Table 1. HNC and FGMs is fabricated using weight percentage of 5 and 10 of nano TiO_2 fillers. Nano- TiO_2 filler is mixed with the vinyl ester matrix by stirring technique which is rotated at 1000 r/min for 30 min. After then, accelerator and hardener are put into the mixture of matrix and filler and stirred gently to avoid the air bubbles formation inside the fabricated specimens. The mixture of nano TiO_2 fillers and vinyl ester matrix are filled into test tubes having the length and diameter of 100 mm and 12 mm, respectively. Fabricated samples were retained at room temperature for one day for curing. Cured HNC specimens are take out from the test tubes. Nano- TiO_2 filler is provided by Intelligent Materials Pvt. Ltd., Chandigarh and vinyl ester matrix material is provided by Sakshi Chemicals, Delhi. FGM specimens are also manufactured with the same weight percentage of nano fillers as it is used to fabricate HNC. The mixture of vinyl ester matrix and nano filler in the test tube is rotated at 1000 rpm for 40 minutes with the help of customised setup to fabricate FGMs. After completing this process, specimens are kept at room temperature for one day for curing.

Table 1 Experimental and theoretical density of HNCs and FGMs

Composite Designation	Composite composition	Experimental density (ρ_e) g/cm^3	Theoretical density (ρ_t) g/cm^3	Void fraction (%)
NV	Neat vinyl ester	1.7943	1.8000	0.3151
VH5	Vinyl ester + 5wt % nano-TiO_2 filled HNC	1.7878	1.8735	4.5732
VH10	Vinyl ester + 10wt % nano-TiO_2filled HNC	1.7111	1.9163	10.6942
VF5	Vinyl ester + 5wt % nano-TiO_2 filled FGMs	1.8204	1.8735	2.8361
VF10	Vinyl ester + 10wt % nano- TiO_2 filled FGMs	1.8257	1.9163	4.7295

2.3 MECHANICAL CHARACTERIZATION

Agarwal and Broutman's formula is used to calculate the theoretical density of HNCs and FGMs [21]. However, experimental density of fabricated specimens is measured as per the ASTM D792 standard. The void content (%) of the fabricated samples is calculated with the help of theoretical and experimental densities as shown in Table 1. Universal testing machine is used for the tensile, flexural and compression test. Tensile and flexural tests are executed as per the ASTM D3039 and D2344 standards, respectively. However compression test is performed as per ASTM D695 standard. Plastic impact tester is used for the impact testing of fabricated composites. Impact test is performed as per ASTM D 256 standard. Rockwell hardness tester is used for hardness (HRL) measurement of HNC and FGMs.

3. RESULTS AND DISCUSSION

VOID FRACTION OF HNC AND FGM

It is very difficult to fabricate voids free filler filled thermosetting based polymer composites. Probability of voids generation is increased with the nano filler reinforcement. Voids inside the nanocomposites affect their mechanical properties. Void content of fabricated nanocomposites is calculated with the help of theoretical and experimental density. Void fraction of neat vinyl ester, HNC and FGMs are shown in Table 1. FGMs have less void fraction as compared to unfilled vinyl ester and HNC. FGMs have less void fraction due to their fabrication technique. Bubbles are collapsed quickly towards the outer periphery of FGMs sample surface. Centrifugal action is the reason for this phenonmena . Therefore, void fraction decreases spontaneously.

3.2 HARDNESS OF HNC AND FGM

Hardness is an important parameter to select any material for specific applications. FGMs samples have the variation in hardness from inner to the surface periphery due to gradation of fillers. Density of filler and matrix play an important role for the gradation. The density of vinyl ester resin is less than nano- TiO_2 filler. Therefore, gradation of nano TiO_2 fillers take place from the center to periphery of the FGM samples under centrifugal casting. Hardness of FGMs samples is estimated in three dissimilar places as revealed in Fig. 1.

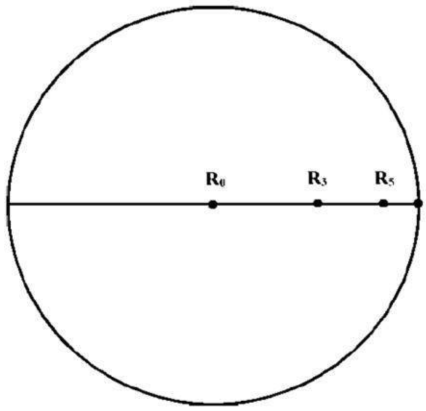

Fig. 1 Schematic representations of zones for micro-hardness measurement

The average value of hardness for three dissimilar places is engaged as the demonstrative hardness value of the FGMs. Average hardness value is 71 HRL and 85 HRL for PF5 and PF10, FGMs samples, respectively. HNCs have lower hardness than FGMs as evident from Fig. 2. The hardness of HNC and their FGMs upsurges with upsurge in the nano TiO_2 filler loading. Neat vinyl ester has less hardness as compared to filler filled nanocomposites.

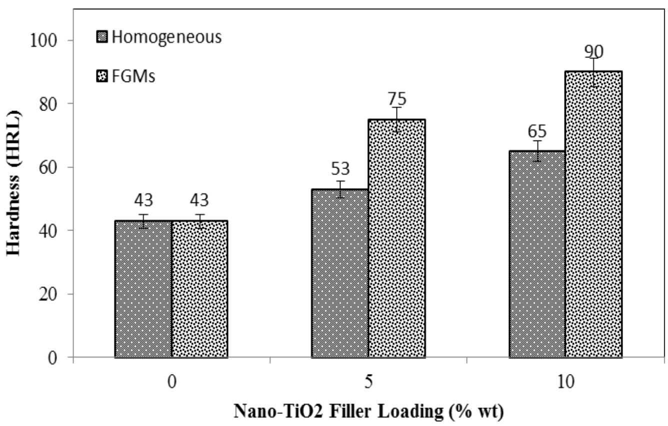

Fig.2 Hardness of HNC and FGM

TENSILE STRENGTH OF HNC AND FGM

This statement is notorious that the strength of composites material is very much depends on the strength of filler and their content in the composite material. Fig. 3 shows the tensile strength of HNC and FGMs. Unfilled vinyl ester has the tensile strength of 20 MPa. This is witnessed from Fig. 3 that tensile strength upsurges with the 5 weight percent of nano TiO_2 filler filling and it is further decreases for 10 weight percent of filler filling. This phenomenon is perceived for FGMs as well as HNC. Tensile strength decreases for 10 weight percent of filler filling due to increase the brittleness and void fraction of the fabricated composites. FGMs have high tensile strength at both weight percentages of filler filling as compared to HNC as observed in Table 1. Tensile strength of 5 weight percent of nano filler occupied FGM is remarkably extraordinary.

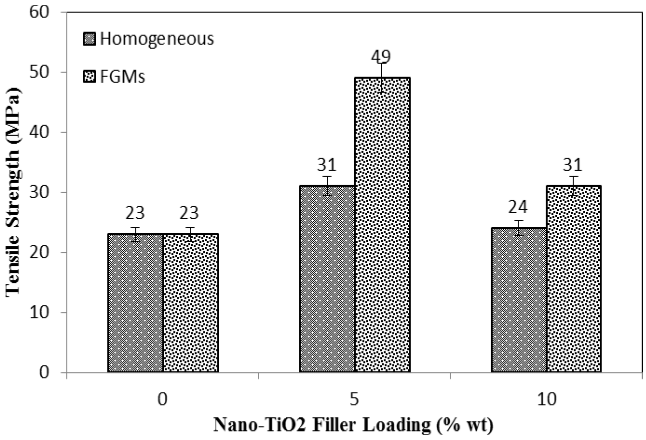

Fig. 3 Tensile strength of HNC and FGM

FLEXURAL STRENGTH OF HNC AND FGM

Fig. 4 shows the beading capability of HNC and FGMs. It is saw that flexural strength of fabricated composites upsurges with the corroboration of the fillers and also increases with the filler loading. FGMs performed better than HNC for both the weight the weight percentage. Flexural strength of neat vinyl ester is 40 MPa. Under flexure loading, voids and crack inside the nanocomposites is closed due to the perpendicular loading to the sample axis. However, loading is parallel to the sample axis under tensile loading causes opening the cracks and voids results in early failure of the samples. As compare to FGMs, nano TiO_2 filled HNCs, have 17% and 21% less flexural strength for 5 and 10 of weight percentage of nano- TiO_2 filler filling, respectively.

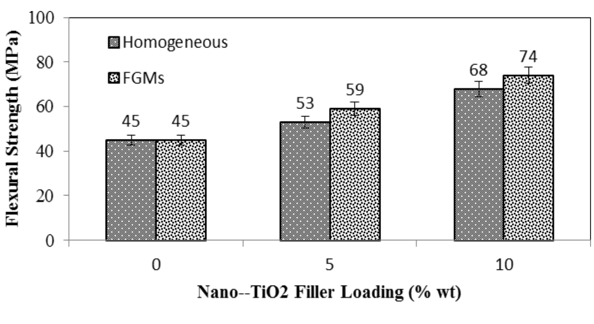

Fig. 4 Flexural strength of HNC and FGM

4.5 COMPRESSIVE STRENGTH OF HNC AND FGM

Compressive strength shows the structural ability of composite materials. Compressive strength capability of HNC and FGMs is given in Fig. 5. Unfilled vinyl ester has the compressive strength of 35 MPa. Compressive strength enhanced for HNC and FGMs with growing the charging of nano- TiO_2 filler. This is witnessed from Fig. 5 that compressive strength of HNC is higher than FGMs for both 5 and 10 weight percentage of nano filler filling. It may happen due to the resin rich reason of the core of FGMs causes less compressive strength.

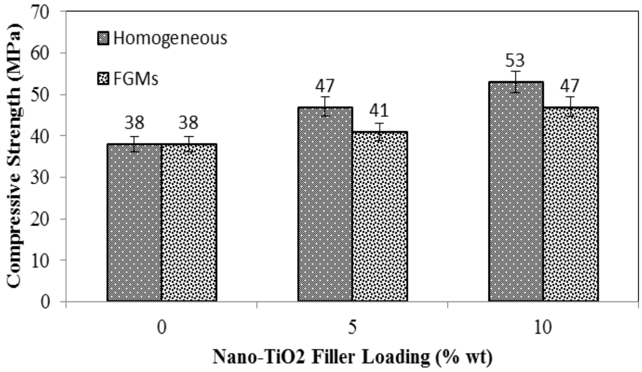

Fig. 5 Compressive strength of HNC and FGM

Impact strength of HNC and FGM

Impact strength of HNC and FGMs is revealed in Fig. 6. The extent of impact strength for unfilled vinyl ester is 0.33 J. The impact strength of HNC and FGMs upsurges with 5 weight percent of nano- TiO_2 filler filling, and it drops to 10 weight percent of filler filling. FGMs have great impact strength as compared to HNC at 5 and 10 weight percentage of filler filling, respectively. The extent of maximum impact strength is 0.78 J for FGMs at 10 weight percentage of nano-TiO_2 filler filling. FGMs have higher impact strength due to temperature-cure gradient effects.

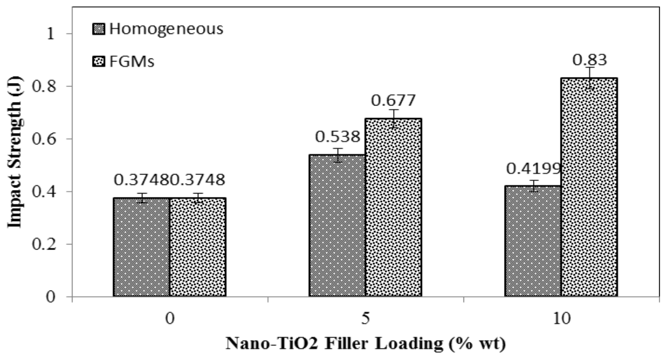

Fig. 6 Impact strength of HNC and FGM

Conclusion

Nano- TiO_2 filled vinyl ester based HNCs and FGMs fabricated successfully.

1. Hardness, flexural and compressive strength increases with increase in the filler loading of nano TiO_2 particulates.

2. Tensile strength of 5 weight percent of nano- TiO_2 filled FGMs and HNC are higher as compared 10 weight percent of nano- TiO_2 filled nano-composite materials.
3. Impact strength of HNC increases with 5 weight percent of filler filling and vice versa is perceived for 10 weight percent of nano TiO_2 filler filling. However, Impact strength of FGMs is upsurges with the upsurge in filler filling.
4. Unfilled vinyl ester has least mechanical properties in comparison to FGMs and HNCs.

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