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Characteristics of Friction Stir Processed UHMW Polyethylene Based Composite

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Abstract. Ultra-high molecular weight polyethylene (UHMWPE) based composites are widely used in biomedical and food industries because of their biocompatibility and enhanced properties. The aim of this study was to fabricate UHMWPE / nHA composite through heat assisted Friction Stir Processing. The rotational speed (**ω**), feed rate (**f**), volume fraction of nHA (**v**) and shoulder temperature (**T**) were selected as the process parameters. Macroscopic and microscopic analysis revealed that these parameters have significant effects on the distribution of reinforcing material, defects formation and material mixing. Defects were observed especially at low levels of (**ω**, **T)** and high levels of (**f**, **v)**. Low level of **v** with medium levels of other parameters resulted in better mixing and minimum defects. A 10% increase in strength with only 1% reduction in Percent Elongation was observed at the above set of conditions. Moreover, the resulted hardness of the composite was higher than that of the parent material.

1. Introduction

Polymer nano composites (PNC's) offer better mechanical properties than pure polymeric materials. With the nanotechnology achievements, PNC's are being fabricated for applications [1] for example biomedical and fuel cell applications [2]. Several techniques have been used to produce PNC's such as Solution Blending [3], and Friction Stir Processing (FSP) [4]. There are limitations of some of the methods. For example, Solution Blending is inappropriate for polymers which are insoluble in solvents [3].

FSP has been observed to be a very useful method for fabricating composites with improved mechanical properties such as hardness, strength etc [5, 6]. FSP was first explored by Mishra et al. [7] as a modification of friction stir welding (FSW) technique, which is a solid state joining process. Simplicity of necessary resources and flexibility regarding applicability make this method suitable for a number of applications.

When nano hydroxyapatite (nHA) particles are mixed with polymer matrix like ultra-high molecular weight Polyethylene (UHMWPE), the resulting composite exhibit features of biocompatibility and enhanced mechanical properties. This fabricated composite could be a better candidate for applications in biomedical and food industries [8,9].

In the light of above facts, the aim of this research was to experimentally investigate the production of UHMWPE / nHA composite through heat assisted FSP. The composite was fabricated by varying various process parameters.

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2. Materials, Experimental Setup and Methodology

In this study, two materials were employed to fabricate the composite. UHMWPE and nHA were utilized as the matrix and the reinforcing material, respectively. UHMWPE was supplied by 'Ningjin County Hongbao Chemical Company Ltd China'. The strength, Percent Elongation and melting range of the as-received polymer sheets were 18.6 MPa, 18.36 mm/mm and 130-138 ^{o}C, respectively. The nHA powder was provided by 'Xi'an Lyphar Biotech Company ltd China'. The average size of the particles was 60 nm with needle like shape and 96 % purity.

Conventional FSP tools perform effectively for metallic materials, but when these tools are applied to FSP of polymeric materials, they do not perform efficiently [10]. Hence, the tool utilized by strand [11] has been improved upon, which consist of a rotating pin, stationary shoulder and a heating system. The shoe shaped shoulder is stationary while the tool pin rotates because a thrust bearing was utilized. A closed loop heating system was responsible for supplying control heating for the process. The volume fraction (v) of nHA powder was estimated by varying the dimensions of the groove. A special fixture was manufactured in order to clamp the sheets during the process. Figure 1 shows the employed fixture, milling machine and FSP tool.

Preliminary experimentations were conducted to set the suitable ranges of process parameters. It was observed that the higher shoulder temperature (T) i.e above 100 ^{o}C lead to material degradation. Moreover, at 100 mm/min feed rate (f), voids formation was observed. Also, volume fraction (v) of 15 % or above resulted in poor mixing of the reinforcing material with the matrix. Moreover, material degradation was observed at high rotational speed (ω) of 2000 rpm. A test plan based on the preliminary experiments was designed. The test plan along with the mechanical tests results are presented in table 1.

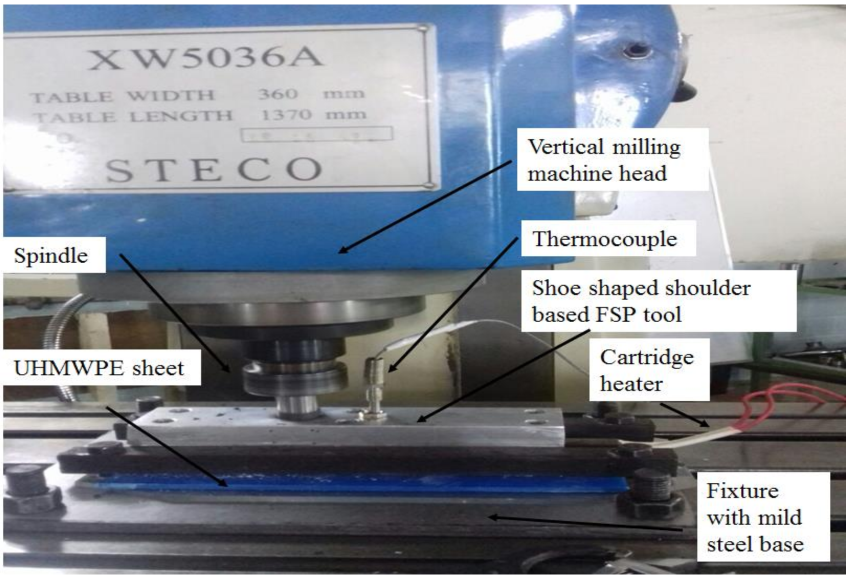


Figure 1. Experimental setup: fixture along with milling machine and specialized FSP tool.

Dwell time of 15 seconds [12] along with tool plunge depth of 0.2 mm were utilized in the processing of the composite. Milling was performed on both sides of the FSPed sheets in order to remove surface irregularities. The tensile tests were performed on Instron Universal Testing Machine at cross head speed of 2 mm/min according to ASTM D638 standard. Tensile properties were calculated from the load-elongation data. Rockwell hardness of the composite was also measured according to ASTM D785. The TESCAN Scanning Electron Microscope was employed to perform microscopic analysis.

Table 1. Test plan along with the mechanical tests results.

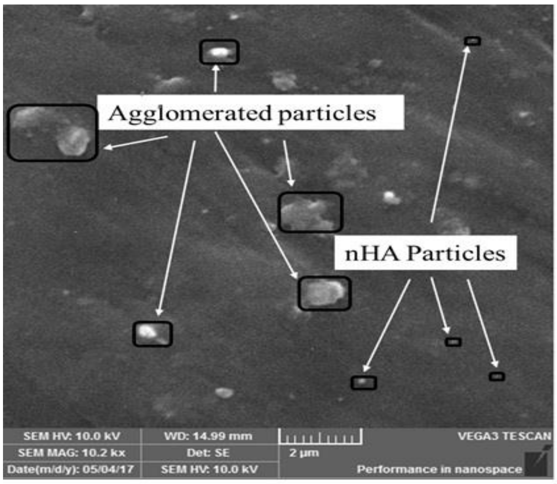
Exp. No.	ω (rpm)	f (mm/min)	v (%)	T (^{o}C)	Ultimate Tensile Strength (MPa)	Percent Elongation (mm/mm)	Rockwell Hardness (HRE)
1	660	48	15	110	12.4	0.228	101
2	660	30	10	110	21.5	1.3	96
3	1200	48	5	65	20.4	8.2	96.8
4	660	48	10	30	3.7	0.15	77
5	660	48	5	65	16	3.43	92.3
6	1200	30	15	30	16.9	0.6	96
Parent Material	-	-	-	-	18.6	8.363	94

3. Results and Discussion

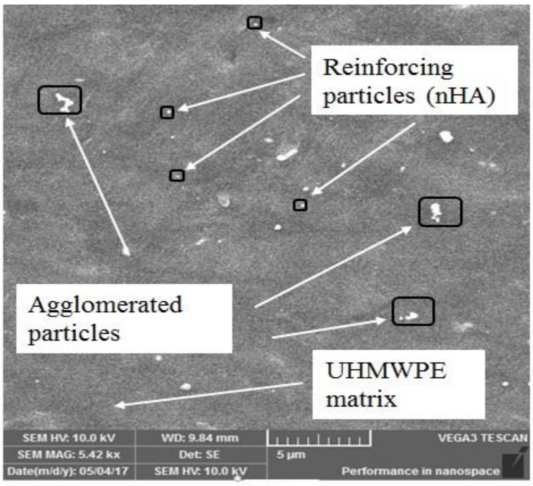
3.1. Microscopic and Macroscopic Analysis

Scanning electron microscopy (SEM) was utilized to investigate the distribution of nHA particles in the matrix and defects in the composite. From figure 2(c), agglomeration of the reinforcing powder can be observed in experiment 6. Very low shoulder temperature (**T)** and high volume fraction of nHA particles (**v**) were the parameters that prevented the materials mixing effectively. Hence, caused defects such as agglomeration and voids. Moreover, experiment 2 also exhibited agglomeration of the reinforcing particles (see figure 2(a)), but no traces of micro voids. It can be observed that due to relatively low content of nHA particles, experiment 3 showed very low agglomeration as compared to experiment 1 and 2 as shown in figure 2(b).

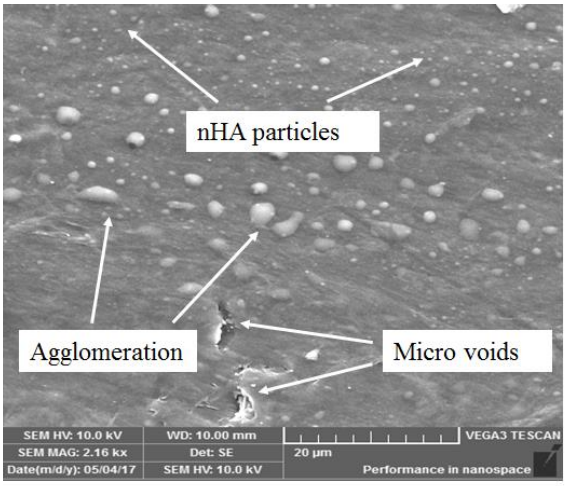
Optical images shows various defects in experiment 4 and 6 (see figure 3). Voids, channels and agglomeration of nHA particles can be observed in these experiments. Moreover, material burning was observed in experiment 2. It shows that combination of high **T** and low **f** lead to material burning / degradation.



(a)

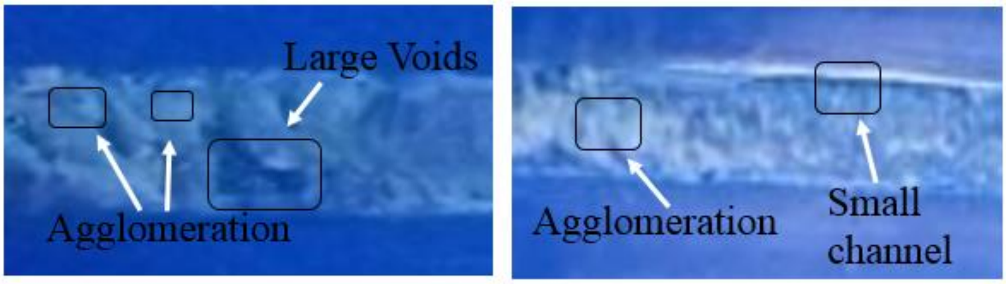


(b)



(c)

Figure 2. SEM images various experiments (a) experiment 2 with high content agglomeration (b) experiment 3 showing low content agglomeration (c) agglomeration and micro voids in experiment 6.



(a) (b)

Figure 3. Defects observed in various experiments: (a) experiment 4, (b) experiment 6.

3.2. Mechanical Properties of the Fabricated Composite

Figure 4 shows a comparison of various mechanical properties of the composite with the parent material. The properties include ultimate tensile strength (UTS), Percent Elongation and Rockwell Hardness (RH). It can be observed that through FSP, mechanical properties of the composite can be enhanced. It can be also observed that experiment 2 showed the highest UTS (increased by 20 %) as compared to the parent material. Moreover, experiment 3 exhibited 10 % increased UTS with only 1 % decrease in Percent Elongation (ductility). On the other hand, experiment 1 showed highest HR (increased by 7.5 %). Hence, as a whole, experiment 3 is considered to be a suitable set of processing conditions. This is due to the fact that the UTS and RH has increased at these set of conditions. Moreover, the ductility has suffered in all the other experiments except experiment 3. Hence, experiment 3 set of conditions are recommended for the fabrication of UHMWPE / nHA composite.

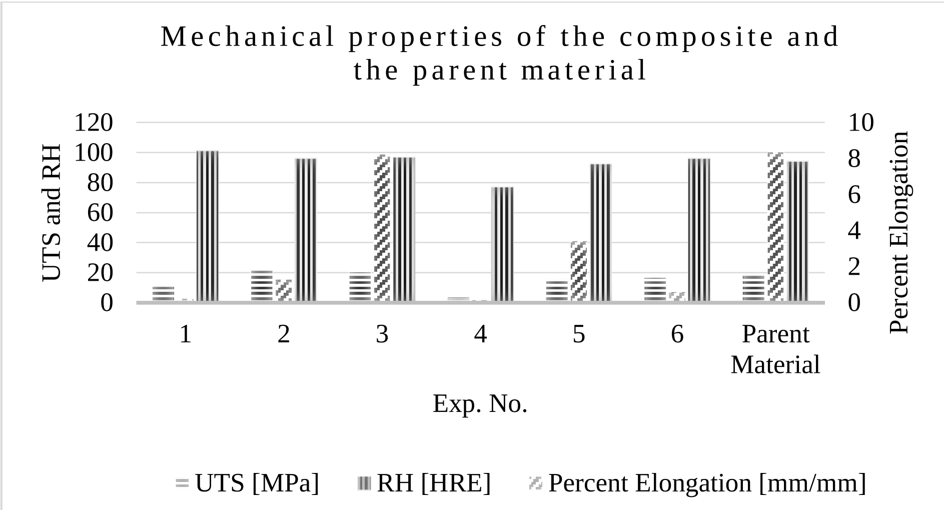


Figure 4. Comparison of mechanical properties of the composite with the parent material.

4. Conclusions

In this study, UHMWPE / nHA composite was fabricated through heat assisted FSP. The properties of the resulting composite were quantified. The processed composite was analyzed through microscopy. It can be concluded that it is feasible to produce polymer composite through heat assisted FSP. Various defects such as voids, channels and agglomeration of nHA particles were observed at low shoulder temperature, high volume fraction of nHA particles and low rotational speed. These defects reduced the mechanical properties of the composite. The conditions suggested for the fabrication of the composites are: (shoulder temperature of 65^{o}C, volume content of 5 %, rotational speed of 1200 rpm and 48 mm/min feed rate). This set of conditions enhance the mechanical properties such as 10 % increase in tensile strength, minor drop of only 1 % in Percent Elongation and increase in Rockwell Hardness by 3 %.

5. Acknowledgement

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6. References

[1] Tanahashi M 2010 *Materials* **3** 1593-619.
[2] Paul D and Robeson L 2008 *Polymer* **49** 3187-204.
[3] Moniruzzaman M and Winey KI 2006 *Macromolecules* **39(16)** 5194-205.
[4] Alyali S, Mostafapour A and Azarsa E. 2012 *Int J Adv Eng Technolv* **3(1)** 598-605.
[5] Sharma V, Prakash U and Kumar B 2015 *J. Mater Process* **224** 117-34.
[6] Singh R, Kumar V, Feo L and Fraternali F 2016 *Composites Part B: Engineering* **103** 90-97.
[7] Mishra RS, Mahoney MW, McFadden SX, Mara NA and Mukherjee AK 1999 *Scr Mater* **42(2)** 163-8.
[8] Wei G and Ma P 2004 *Biomaterials* **25** 4749 **-** 57.
[9] Pan Y and Xiong D 2009 *Wear* **266** 699–703.
[10] Troughton MJ 2008 *Handbook of plastics joining: a practical guide* vol 2 ed MJ Troughton (Norwich, NY: William Andrew Inc) pp 131-134.
[11] Strand S 2003 *proc Conf Electr Manuf Coil* (Provo, Utah : IEEE) pp 321-327.
[12] Mostafapour A and Taghizad Asad F 2016 *Sci Tech Weld Join* **21(8)** 660-669.