Manufacturing of Nano-diamonds Reinforced Aramid Matrix Nanocomposites for Improved Mechanical Performance

[1]Fatima, [2]Menahil Mahmood, [3]Mehwish Yaqoob, [4]Usama Zaheer, [5]Saima Shabbir and [6]Tayyab Subhani
Department of Materials Science and Engineering,
Institute of Space Technology, Islamabad
[1]fatima2971@gmail.com
[2]menahilmahmood93@gmail.com
[3]mehwishyaqoob434@gmail.com

Abstract - A novel class of nanocomposites was produced using nano-diamonds (NDs) as nano-reinforcements in aramid matrix. NDs were functionalized by ozone-treatment before incorporating in aramid, which was first synthesized and functionalized by solution poly-condensation of aromatic diamines and di-acid chlorides in amide solvent. The loading of NDs in the composites was maintained at 1wt%, 3wt% and 5wt%. The quality of dispersion of NDs in the aramid was observed through scanning electron microscopy while an increase in the mechanical properties was witnessed by the help of hardness, impact, flexural and tensile testing. It was found that the functionalization of both the nanodiamonds and the matrix resulted in an improved dispersion quality of NDs, which enhanced the mechanical performance of the composites.

Keywords - nanocomposites, nano-diamonds, aramid, mechanical, dispersion

I. INTRODUCTION

Nanotechnology rules this age by rendering revolutionary advancements in different fields of science. Nanomaterials research takes advantage of the development in materials computation and synthesis at microscopic level. Nanocomposites possess better mechanical and thermal properties as compared to other high performance materials. A number of combinations of nanofillers may be incorporated into the polymer matrices to yield novel composites.

Nanodiamond powder is well known for its unique surface structure along with high thermal behavior, magnificent electrical and mechanical properties and extraordinary tribological properties. These properties make it worthy to be used in various technology fields such as polishing of artificial crystals, reinforcements of plastics, friction modification and wear resistant coatings [1-4]. Functionalizing nanodiamonds would result in the appearance of characteristic surface groups on the nanodiamonds structure which would most probably interact with polymer chains ensuring good adhesion between the polymer and nanodiamonds. Hence the properties of the polymer are improved however, so far, less attention has been given towards the incorporation of nanodiamonds as the reinforcement material or the improvement in polymer matrix properties [5-11].

Industrially developed in the 1960s, aramids became a combination of science research and application at an earlier stage. Aramid fibers are renowned for their high strength and modulus, low density and high impact strength in the composites. Hence, aramids are used in applications where high tenacity is required.

These days, high performance polymer composite materials have wide application and sometimes are challenged by hard working conditions like those of extremely high temperature and humidity etc. [12-14]. Therefore, these materials need to possess superior mechanical properties and resistance to degradation in order to provide safety and to ensure economic efficiency.

Hence, for this purpose, nanodiamonds have been incorporated in an aramid matrix in various proportions and then analyzed by various characterization techniques to study its properties.

II. PROCEDURE

A. Materials:

- Aromatic Diamine
  - i. 4-4’ Oxydianiline ($C_{12}H_{12}N_2$)
  - ii. m-Phenylenediamine ($C_6H_8N_2$)
- Aromatic diacid chlorides
  - i. Isophythaloyl chloride ($C_8H_4Cl_2O_2$)
- Solvent
  - i. N,N-Dimethylacetamide (DMAC)
- Nano diamonds (ND)

B. Functionalization of nano diamonds:

As received nanodiamonds, as shown in the following figure 2.1 were acid functionalized by the help of ozone treatment. Functionalization can modify the surface properties of nanodiamonds and hence can be easily dispersed in the matrix without forming agglomerates.

Fig 2.1 As received nanodiamonds

C. Synthesis and functionalization of Aramid matrix:

Polycondensation reaction was used to synthesize the aramid by reacting diamines with diacid halide using solution polymerization route. 0.255g of 4, 4'-Oxydianiline and 0.135g of 1, 3-phenylenediamine were added in the flask followed by 10ml of solvent (N,N- Dimethylacetamide) and were left to mix by polycondensation reaction at room temperature. This mixture was allowed to stir for 30 minutes then 0.507 g of (IPC) Isothaloylchloride was added to the flask. The whole solution was again left for 2 hours of stirring. The color of the reaction mixture thus obtained was dark brown. Basic functionalization of the aramid chains was carried out by end capping with amine groups by adding 1% excess of diamines and was allowed to stir for another 30 minutes under the same conditions. Fig 2.2 shows the schematic of aramid matrix manufacturing.

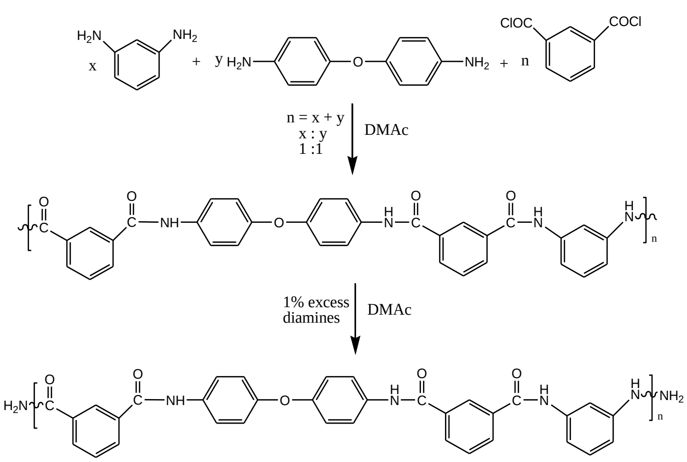

Fig 2.2 Scheme of synthesis and functionalization of aramid matrix

D. Fabrication of Nano-composites:

For the fabrication of 1wt% nanodiamonds reinforced aramid matrix nanocomposites film, 1wt% ozone functionalized nanodiamonds were added in above prepared mixture (basic functionalized aramid matrix). The mixture was left to stir for 17 hours and was poured into a petri dish. Then drying was done by placing the petri dish into the vacuum oven for 8 hours at 97 ^{o}c.

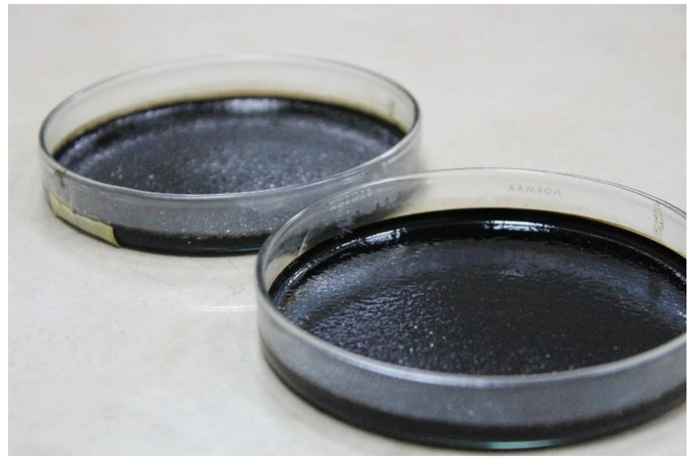

Fig 2.3 Fabricated Nanodiamonds reinforced aramid matrix

For the fabrication of 3wt% and 5wt% nanodiamonds reinforced aramid matrix, similar procedure was repeated provided the amount of nano reinforcements added were changed respectively.

III. RESULTS & CONCLUSION

High strength and toughness are the two unique properties of aramid. When aramid is combined with nanodiamonds, an improvement in its properties is expected. The goal of this system will be achieved by making various different combinations of the matrix with 1,3 and 5wt% reinforcements and then comparative analysis these samples will be conducted with a number of characterization techniques including thermo gravimetric analysis (TGA), Fourier transform infrared spectroscopy (FTIR) and Scanning electron microscope (SEM) to find the optimum properties of the nanocomposite.

E. SEM Results:

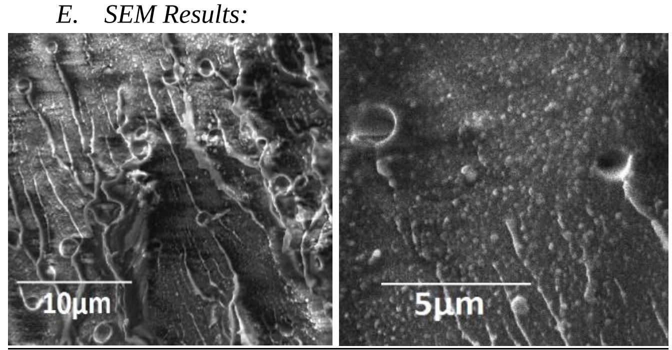

Fig 3.1 SEM images of 1wt%

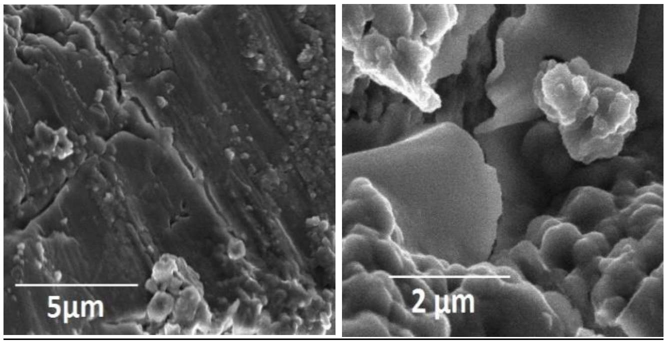

Fig 3.2 SEM images of 3wt%

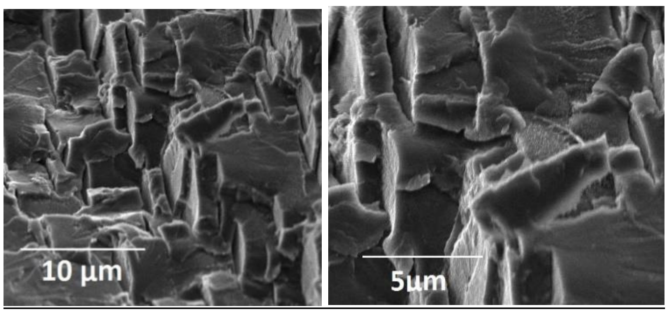

Fig 3.3 SEM images of 5wt%

The above mentioned SEM images of the nanocomposite confirm uniform dispersion of functionalized nanodiamonds as nanoreinforcements in the aramid matrix resulting in the novel combination of this nanocomposite.

In figure 3.1 SEM images of 1wt% nanodiamonds reinforced aramid matrix reveal more porous structure as compared to 3wt% and 5wt% samples. Figure 3.3 represents the SEM images of the sample with 5wt% nanodiamonds reinforced aramid matrix which shows that the fractural properties of the 5wt% sample have been increased as compared to 1wt% and 5wt%. Thus we can say by looking at the above images of SEM that by increasing the amount of reinforcement in the aramid matrix, porosity decreases and fractural properties increase.

F. FTIR Results:

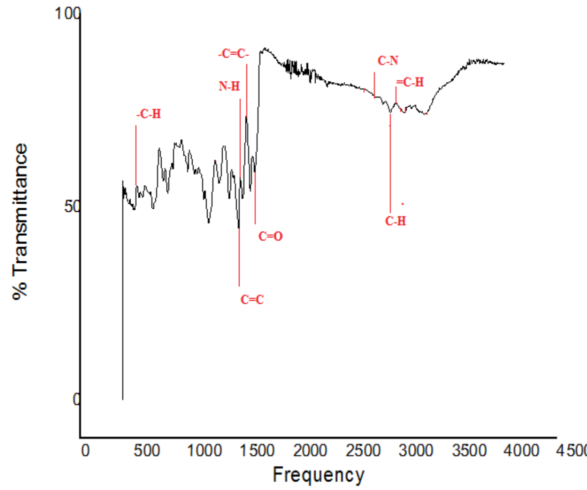

Fig 3.4 FTIR result

Peaks in the above spectra show the presence of amide linkage and carbon-carbon double bond which confirms uniform functionalization of reinforcement and formation of aramid matrix thus ensuring the presence of amide linkages in this novel combination of the nanocomposite. The peak values for the system under observation are summarized in the given table:

Functional Groups	**Observed Values**	**Literature Values**
C-H	2914.98	2820-2810
N-H (amide bond 2)	1513.41	1650-1550
C-N	2845.26	2750-2650
-C=C- in benzene ring	1453.31	1510-1450
-C-H	772.75	770-730
=C-H	2914.98	3100-3000
C=C	1513.41	1600-1500

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