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IMPROVING THE WEAR RESISTANCE OF POLYVINYL CHLORIDE SURFACE BY USING THE FRICTION STIR PROCESSING TECHNIQUE

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Friction Stir Processing is considered one of the essential methods for improving the surfaces of polymeric materials by adding reinforcing particles in specific ratios to form a composite material with better surface properties than the properties of the base material. The Friction Stir Processing technique was employed in the present investigation to introduce graphite particles onto the polyvinyl chloride surface. Various volumetric ratios of 5, 8, 11, 14, 17, and 20% were used for the incorporation of graphite particles. Mechanical tests (flexural strength, hardness, and wear resistance) were carried out. The experiments demonstrated a noteworthy enhancement in the measured characteristics, with the most notable outcomes observed when the graphite content was increased by 20%. Consequently, this investigation determined that applying the Friction Stir Processing technique effectively reinforced the polyvinyl chloride surface by forming a successful surface composite.

Keywords: friction stir processing, composite materials, polyvinyl chloride, graphite particles, mechanical properties

1 INTRODUCTION

Composite materials are the ideal choice for overcoming the continuous problems of technological innovation. They offer unique properties that differ from traditional materials, such as lightweight in addition to high performance for use in the development of the aerospace industry, cars, electronics, packaging, and high-tech structures [1]–[3]. When structural parts need to withstand friction and wear loadings in use, composite materials are utilized more commonly. Many of these composites fill a metallic, polymeric, or ceramic matrix with short fibers. Others have a continuous fiber-reinforced structure that is arranged as woven textiles or multidirectional laminates while keeping the qualities of the base material, surface composites show improved attributes of composites [4]. A variety of surface modification techniques, including high-energy laser melt treatment [5]–[7], high-energy electron beam irradiation [8], [9], plasma spraying [10], cast sinter [11], and casting [12], have recently made it feasible to fabricate surface metal-matrix composites. Friction Stir Processing (FSP) is a solid-state technique that improves the microstructure by homogenizing the structure and fine-tuning the grain size. It is a suggested method for creating surface composite layers made of lightweight materials because it produces a consistent distribution of reinforcement particles in the surface of the refined matrix microstructure up to a given depth without changing the characteristics of the mass. It thus enhances mechanical characteristics [13]–[15], Moreover, the procedure has the potential to enhance the surface characteristics of the material, including increased resistance to abrasion, corrosion, fatigue life, ductility, hardness, strength, and wear without altering the overall properties of the material [16]. FSP was first described by Mishra et al. (1999) as a modification of friction stir welding (FSW), a technique developed at The Welding Institute (TWI), UK, in 1991. The first FSP-produced superplastic aluminium alloy has ultra-fine grain size and significant grain boundary misorientations. By creating a SiC (0.7 µm)-5083 Al composite layer, Mishra et al. addressed FSP as a novel fabrication process for surface composites. They demonstrated that the tool traverse speed impacts the bonding between the composite layer and that the tool's plunge depth during processing impacts the incorporation of SiC particles. The microhardness of the surface composite reinforced with SiC was almost twice as hard as the substrate consisting of 5083 Al alloy [17], [18]. The simplicity, speed, and variety of materials that can be employed as reinforcement in the composite are what give FSP technology its wide range of possible applications. The development of the composite microstructure in the plasticized matrix and the efficient and regulated insertion of the reinforcing phase into it is made possible by a number of methods. The groove and hole technique and direct friction stir processing are the most crucial ones [19]. In some technical applications, of thermoplastic polymer materials' surface or joint characteristics such as impact, hardness, wear resistance, and core ductility, are more important than the general material qualities. Due to the growing popularity of FSP, which was previously only possible with aluminium alloy, composite fabrication of polymer-based matrix is now produced [20]. Unfortunately, the mentioned techniques for handling materials in large quantities and on their surfaces come with several disadvantages. These include issues such as the clustering of additive particles and their uneven dispersion throughout the material's bulk and surface, the creation of undesired phases and interfacial reactions caused by high processing temperatures, the occurrence of multiple defects in surface layers treated with ion implantation, the development of amorphous layers when exposed to high radiation doses, the requirement for thermal treatment or other supplementary processing approaches, the use of complex processing machinery, low efficiency during processing, and more [21]. FSP is a good solution to the abovementioned issues because it is carried out at temperatures lower than the melting point of materials [22], [23]. By including graphene in the manufactured aluminium matrix composites. Huijie Zhang et al. summarized the possibilities of employing the FSP approach to increase the efficiency of aluminium metal. They also looked at how the FSP process parameters affected the composite material's structural qualities. By examining the results of tests on mechanical characteristics and corrosion resistance, it became clear that there had been a considerable change in the aforementioned properties, which had been significantly enhanced by the FSP technique [13]. Using the FSP technique, Jicheng Gao et al. discussed the possibility of incorporating copper particles into high-density polyethylene to create a composite material. Test results revealed that the copper particles were uniformly distributed throughout the base material, and some mechanical properties, such as the base's surface hardness, had improved [15]. Dhanunjayarao et al. investigated the effects of the addition of graphite particles on the mechanical characteristics of hybrid polymer (glass\jute) composites. The obtained specimens were subjected to various mechanical tests. The results displayed that the addition of graphite enhanced the mechanical properties of the composite [24]. Nevertheless, novel uses for natural fibers in polymeric composites are being developed in a number of industries, including bearing manufacturing, industrial applications, the production of automobile parts, and structural and non-structural applications [25]. Other applications of FSP in the field of polymer surface reinforcement can be found in the references [1], and [26].The present work aims to improve some mechanical properties, especially the wear resistance of the polyvinyl chloride (PVC) surface, by adding graphite particles in different proportions to the surface of the PVC, while keeping the properties of the matrix without change.

2 EXPERIMENTAL PROCEDURES

2.1 Materials

2.1.1 PVC

PVC used in this research was obtained by SIMONA AG / Germany. After polyethylene and polypropylene, PVC is the world's third most engineered plastic polymer.

2.1.2 Reinforcement Particles

Graphite particles were added at various ratios to improve the mechanical properties of PVC to produce a polymeric composite. Graphite's particle size distribution is depicted in Figure 1, the mean diameter for these particles was 25 μm.

2.1.3 Experimental Work

PVC sheets were provided with a thickness of 5 mm and machined to the required dimensions (200 mm x 100 mm), after which longitudinal slots were implemented in the center of the PVC sheets, 8 mm wide and 150 mm long, in different depths 1.67 mm, 2.01 mm, 2.35 mm, and 2.68 mm commensurate with the amount of graphite that will be placed in these slots, to keep the graphite particles inside the slot, also to prevent the particles from escape during the implementation of the FSP technique. The dimensions of the slots at different depths were calculated using the volume fractions of the secondary component of the matrix material. PVC covers were machined with a thickness of 1 mm and dimensions that matched the groove cut out in the specimens. The graphite particles were covered with these coverings. Figure 2 shows the specimen's appearance and dimensions. Table 1 displays the suggested particle percentages of graphite in the test specimens.

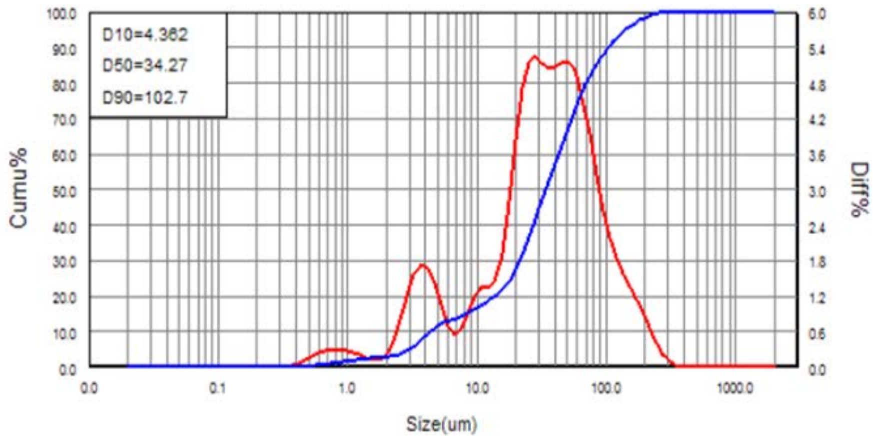

Fig. 1. Graphite powder's particle size distribution

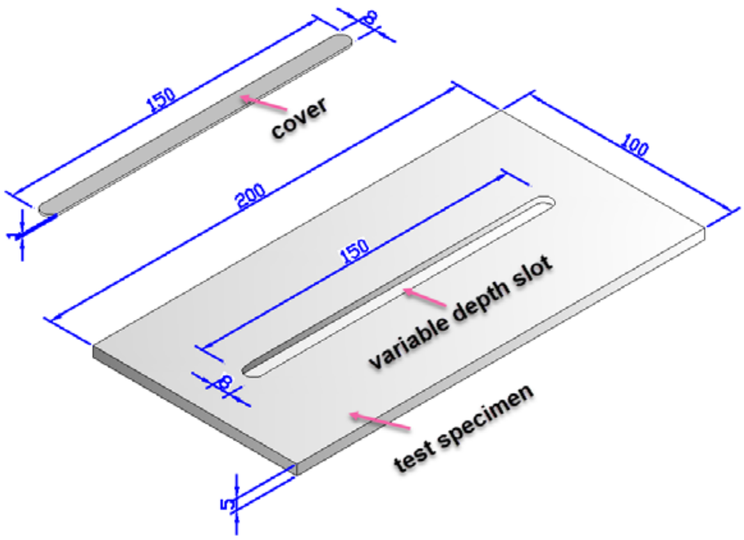

Fig. 2. The shape and dimensions of the specimen

Table 1. Percentage of Graphite particles in the test specimens

Specimen No.	Graphite particles Percentage (%)
1	100% PVC
2	95% PVC: 5% Graphite
3	92% PVC: 8% Graphite
4	89% PVC: 11% Graphite
5	86% PVC: 14% Graphite
6	83% PVC: 17% Graphite
7	80% PVC: 20% Graphite

In the FSP process, a shoe-shaped tool [27] was utilized, its function is to generate sufficient heat to soften the PVC material and spread graphite particles in the area it passed through by stirring generated by the pin, forming the composite material, to form the composite material. The tool is illustrated in Figure 3. It is made of tool steel, has a 20 mm shoulder diameter, and a 3 mm pin height. The pin was made of two parts in the shape of a crescent, and each piece was installed on the circumference of a circle with a diameter of 16 mm so that the two pieces were opposite each other.The purpose of this was to facilitate the mixing of graphite particles with the PVC material to form a composite material. The shoulder and pin were positioned on a thrust bearing. The assembled tool is then placed on an aluminium plate.

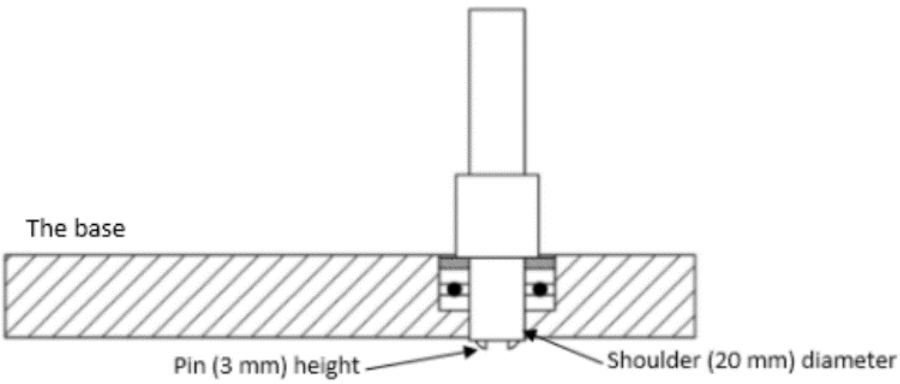

Fig. 3. Sketch of the shoe-shaped tool

A plunge depth of 0.5 mm (the depth at which the tool shoulder enters the top surface of the workpiece) [28], [29], a tool travel speed of 24 mm/min, and a tool rotational speed of 492 RPM were used with all specimens in the FSP. Before the longitudinal movement started, a dwell time of 30 seconds was applied and the specimen’s surface was softened during the plunge stage, creating a good-quality surface. then the tool started traveling longitudinally along the process line. Before beginning the FSP process, the tool was moved so that its center was identical to the center of the slot containing graphite particles. When the FSP process started, the tool worked to disperse the graphite particles below it, which were soft due to the heat produced by the friction between the tool and the specimen's surface. As a result, the production of the composite material began. Using a vertical milling machine, FSP was completed. Knuth, a milling machine built in China, was employed.

3 MECHANICAL TESTING

3.1 Flexural strength

The flexural strength, maximum shear stress, and flexural modulus were measured using a three-point bending test on a universal testing machine (type WDW 200 E, made in China). All tests were conducted at room temperature 23°C and atmospheric pressure. specimens were taken from composite material sheets following ASTM D790 standards.

3.2 Hardness

The Durometer hardness type shore D, which has a graduation scale for the hardness number 0–100, was used to calculate the hardness number. The applied load was 50 N and the measuring time was 15 seconds, according to ASTM-D2240-03. The specimen's dimensions were 20 mm in length, 20 mm in width, and 5 mm in thickness as per ASTM-D2240-03. The reported values for hardness are the mean of 10 readings for each specimen.

3.3 Wear Resistance

The wear resistance experiments were carried out in a pin-on-disc device model (Micro test MT 4003) made in Spain, according to ASTM G 99 [30]. The specifications were as follows: ball diameter 6 mm, track radius 6 mm, disc rotation 200 RPM, normal load 10 N, and test duration 5 and 10 minutes.

4 RESULTS AND DISCUSSION

4.1 Flexural Behavior Test

Figures 4-6 display primary effect graphs for each variable of the additional graphite particles to the matrix material on flexural strength, flexural modulus, and maximum shear stress. In other words, when the graphite particles ratio increased from 5 to 20%, flexural strength, flexural modulus, and maximum shear stress increased by roughly {(26 to 36.8 MPa), (2 to 3.8 GPa), (1.083 to 1.533 MPa)} respectively, as illustrated in the figures, the outputs increase continuously with the increase in a percentage of particles content. Based on the aforementioned findings, the types of fillers used, their ratio in the mixture, and the degree of compatibility between the particles and matrix material all affect how quickly the flexural strength, flexural modulus, and maximum shear stress values of prepared composite specimens increase.

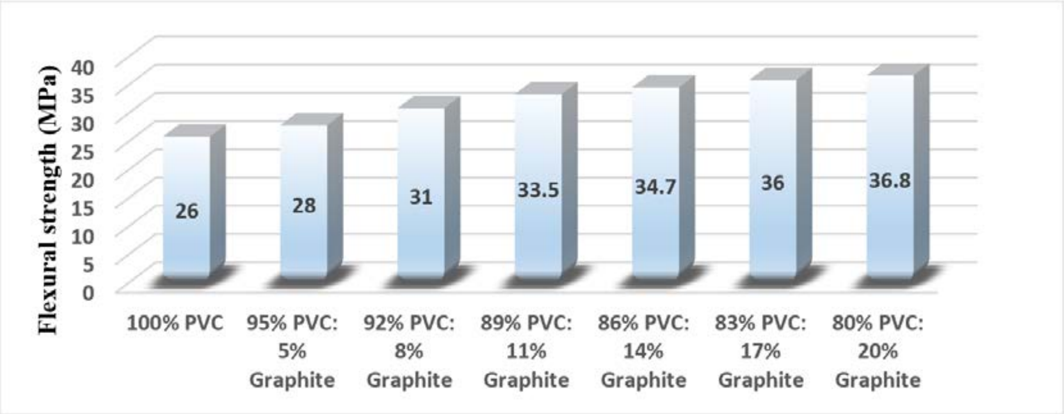

Fig. 4. Flexural strength for composite material as a function of graphite particles

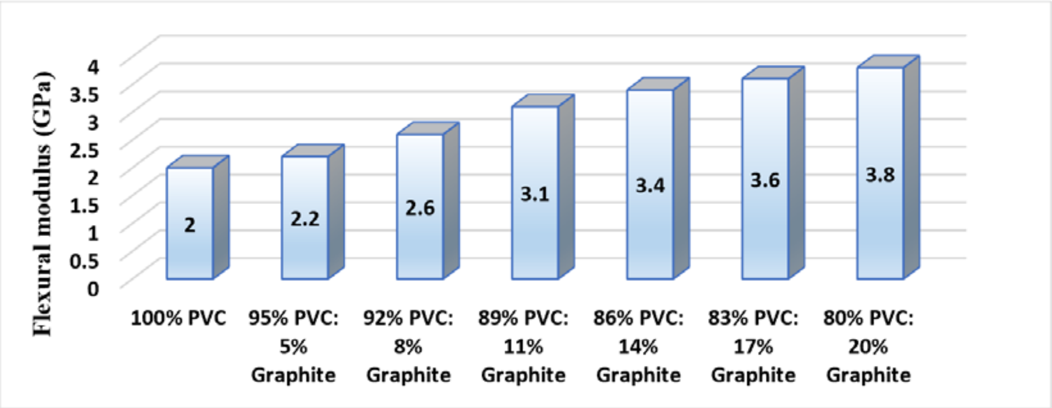

Fig. 5. Flexural modulus for composite material as a function of graphite particles

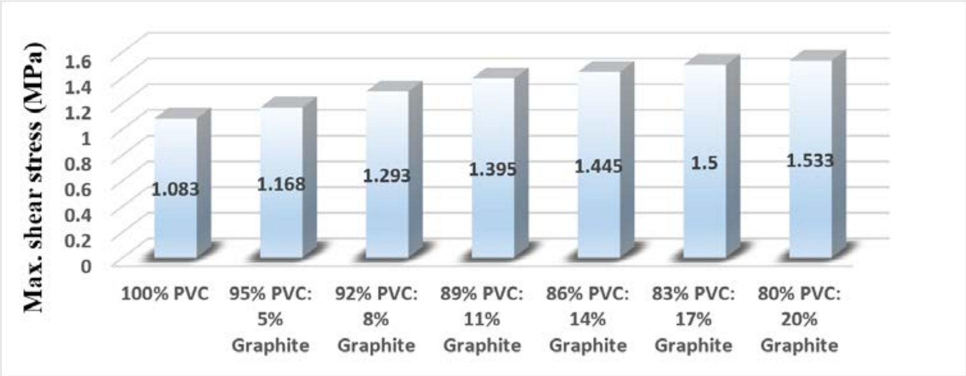

Fig. 6. Maximum shear stress for composite material as a function of graphite particles

4.2 Hardness Test

The main effect charts for the impact of adding graphite particles on hardness are shown in Figure 7. The hardness values are only slightly influenced by each variable. The effect of increasing the ratio of graphite powder addition from 5 % to 20 % is minimal because the increase in the hardness number is negligible. These findings were focused on the type of reinforcement powders added to the polymeric matrix via the friction stir processing technique.

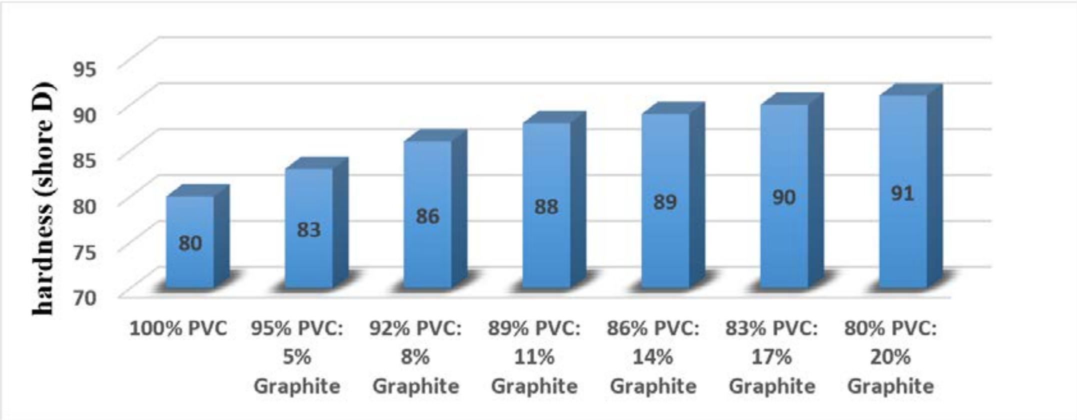

Fig. 7. Hardness for composite material as a function of graphite particles

4.3 Wear Resistance Test

For sliding periods of 5, 10, 15, and 20 seconds, the experimental findings of weight loss and wear rate of polymer composite specimens are shown in Figures 8 and 9. Figure 8 shows that the weight loss rate of the analyzed specimens is nearly constant over the periods 5, 10, 15, and 20 seconds. Due to the type of additive that has higher wear resistance, the graph also shows that the base material PVC obtains the maximum weight loss. The results reveal a considerable improvement in the quantity of wear resistance, and the best results are achieved for the sample manufactured from 80% PVC, and 20% Graphite. Figure 9 illustrates how fillers affect wear rate. Because the particles act as bearings and demonstrate that the adhesion between the polymer materials and fillers is sufficient, showing that there are no voids in the material surface, these results are consistent with some of the results attained.

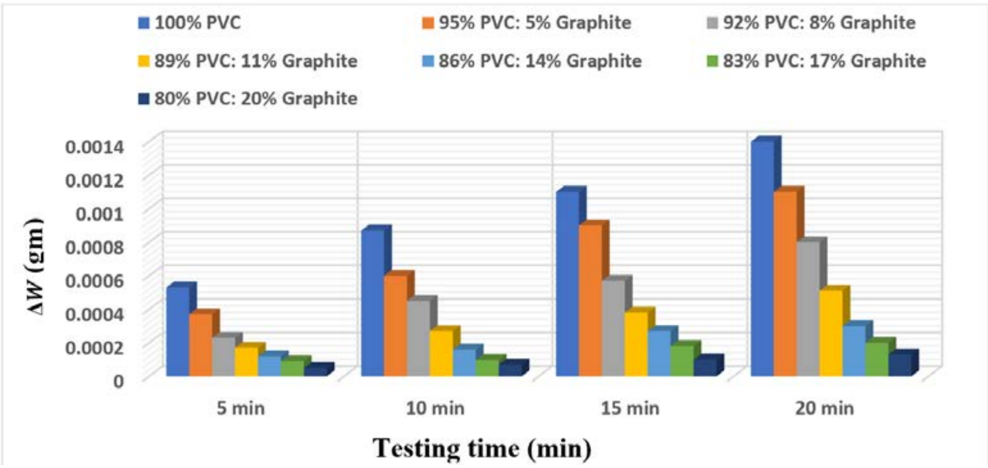

Fig. 8. Weight loss values for specimens

5 CONCLUSIONS

In this study, PVC as a matrix material was reinforced with different percentage ratios of 5, 8, 11, 14,17, and 20 % of graphite particles successfully fabricated by the FSP technique. It has been found that the addition of particles has a significant impact on the mechanical properties of the polymer. The outcomes of the experiments could lead to the following conclusions:

1. There is a significant improvement in the (flexural strength, hardness, and wear resistance) of all composite materials compared with the matrix material.
2. The best configuration for the parameters is 80 % PVC and 20 % Graphite.
3. Each variable has only a small impact on the hardness values.
4. The particles act as bearings, based on the improvement of the mechanical properties, this proves that there are no voids in the surface of the material.
5. Friction stir processing has been widely applied to change the microstructure and characteristics of metal and composite materials, but its usage in polymers, particularly PVC, to increase wear resistance is relatively new and novel.

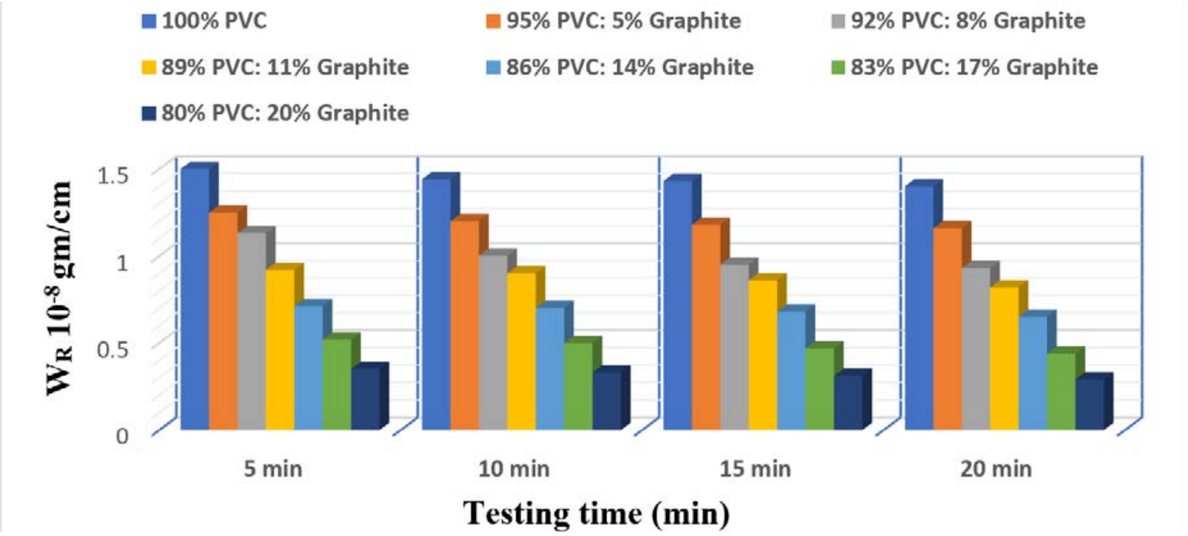

Fig. 9. Wear rate values for specimens

6 ACKNOWLEDGMENTS

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