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WEAR BEHAVIOR OF CERVICAL FUSION PLATES FABRICATED FROM POLYETHYLENE REINFORCED BY KEVLAR AND CARBON FIBERS

Eyad M. A., Ali W. Y. and Nabhan A.

Production Engineering and Mechanical Design, Faculty of Engineering, Minia University, EGYPT.

ABSTRACT
The cervical spine plays an essential role in limiting the physiological ranges of motion in the neck. However, traumatic loading such as that experienced in automotive crash and other scenarios can lead to ligament damage and result in neck injury. The objective of the present study is to investigate the wear behavior of cervical fusion plates fabricated from polyethylene reinforced by kevlar and carbon fibers as alternative of anterior cervical disk fusion arthroplasty. Cervical artificial plates made of high-density polyethylene (HDPE) reinforced by carbon fibers (CF) and kevlar fibers (KF) were tested using reciprocating wear machine.

It was found that the tested composites free of reinforcing fibers showed relatively higher wear values compared to composites reinforced by CF or KF. As the volume content of the tested fibers increased, wear decreased. Besides, composites reinforced by KF offered lower wear values than that caused by composites reinforced by CF. It seems that improvement in wear may be attributed to the strengthening effect of the tested fibers, where they withstand the shear and tensile stresses inside the matrix of the composites.

KEYWORDS
Spinal implants, carbon fibers, kevlar, high density polyethylene, wear, coefficient of friction.

INTRODUCTION
Spinal implants are frequently used in the treatment of spinal injuries and disorders. A successful healing process rely on the stability and resistance to failure of the spinal implant because of spinal systems implants are continuously subjected to static and dynamic loads within their lifetime, [1 - 3]. Biomechanical modification to any spinal element that could affect the vertebral column stability has been defined as spinal instability. although the preceding definition may appear an intuitive concept, measuring the amount of spinal instability and advising the best treatment, represents a challenge for the scientific and medical community, [4, 5]. One of these challenges is the high rigidity of the fusion construct may produce abnormal stresses on the intervertebral discs and facet joints at adjacent levels, and the increased loading over time could cause regional hypermobility and disc degeneration at adjacent segments which will lead to adjacent segment degeneration (ASD), [6 - 15]. For instance, the elastic modulus of titanium which is the primary material used in lumbar fusion operation, is much greater compared with

bone, which may eventually significantly change the distribution of the load at the instrumented vertebral segments, [16 - 18]. Therefore, biocompatible polymers implants are becoming more popular for use in orthopaedic surgery. These implants offer sufficient stability for fusion but at a reduced stiffness, [6, 19]. In recent years, the expansion of composite materials has enabled breakthrough in the design of modern prosthetic and orthopaedics devices.

At present, fibre reinforced polymer composites are the most exceedingly used multiphase materials in orthopaedics. In addition, most of today's upper- and lower-limb prostheses are now made from composites with underlying polymer matrix. Convenient polymer matrix composites can resemble the properties of bone and so have significant advantage as a replacement material. Of course, other aspects including biocompatibility, practicality and costs are also important factors, [20 - 23]. High density polyethylene (HDPE) composites reinforced with Kevlar and carbon fibres were introduced into the field of cervical fusion due to their resistance for chemical, wear, corrosion properties in an attempt to solve drawbacks of conventional stiff constructs and reduce the loading on adjacent segments. These might also display a great structural integrity to the implants against various loads such as mechanical, buckling, flexural, buckling, compressive, torsional and shear, [24]. Although cervical fusion plates require a sufficient degree of flexibility to fulfil its purpose, that high range of neck movement will cause a relative motion at the contact between vertebra bone and fusion plate at extreme ranges.

In this study, the wear behaviour between reinforced HDPE and cervical bones is examined to ensure the integrity of the alternative approach.

EXPERIMENTAL

High-density polyethylene (HDPE) is a thermoplastic polymer produced from the monomer ethylene. (HDPE) is a very inert material with very low tissue reactivity. It has been used as bone and cartilage substitutes since 1940s. Mechanical properties of (HDPE) are showing in table 1.

Table 1 mechanical properties of (HDPE) provided from supplier.

Property	Value
Density (g/cm3)	0.96
Surface Hardness	68
Tensile Strength (MPa)	32
Flexural Modulus (GPa)	1.25
Melting Temp. Range (°C)	120 - 180

Table 2 mechanical properties of (CF) provided from supplier.

Property	Value
Tensile Strength (MPa)	3530
Tensile modulus (GPa)	230
Density (g/cm3)	1.76

Carbon fibers (CF) (graphite) are fibers of 5 to 10 micrometres in diameter and composed mostly of carbon atoms. Carbon fibers have several advantages including high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion. These properties have made carbon fiber very popular in aerospace, civil engineering, military, and motorsports. However, they are relatively expensive when compared with similar fibers, such as glass fibers or plastic fibers. Mechanical properties of (CF) are showing in table 2.

The schematic representation of cervical spine with fusion plate made by (HDPE) composite showing the difference between neutral and (90°) turn position is shown in Fig. 1.

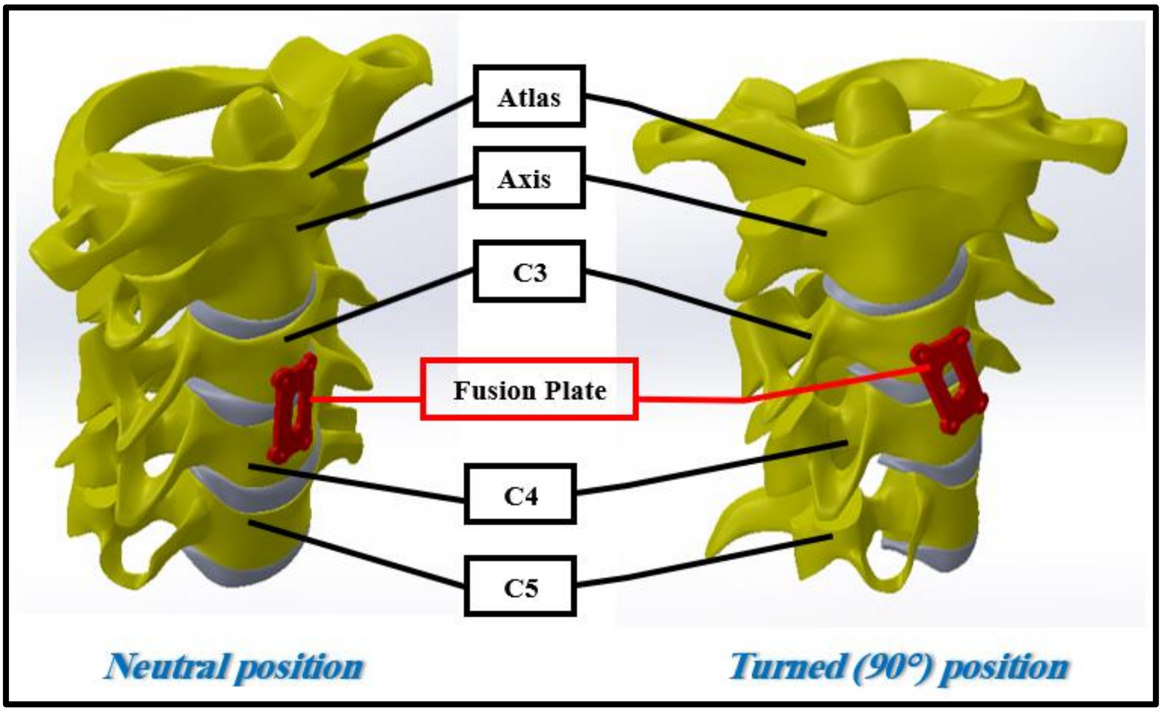

Fig. 1 schematic representation of cervical spine with fusion plate made by (HDPE) composite showing the difference between neutral and (90°) turn position.

Kevlar is a heat-resistant and strong synthetic fiber, related to other aramids such as Nomex and Technora. Typically, it is spun into ropes or fabric sheets that can be used as such or as an ingredient in composite material components. Kevlar has many applications, ranging from bicycle tires and racing sails to bulletproof vests, because of its high tensile strength-to-weight ratio; by this measure it is five times stronger than steel. It also is used to make modern marching drumheads that withstand high impact. It is used for mooring lines and other underwater applications. Mechanical properties of kevlar are showing in table 3.

Reinforced cervical fusion plates were constructed using a rectangular die to produce multiple specimens in one plate in dimension of 120 × 160 and 4 mm thickness. Fig. 2 shows the die design and its components. The spacer has two main functions, the first is to avoid any leak during melting of HDPE and the second is to reach the desired specimen thickness. Therefore, a layer HDPE powder is placed on lower die inside the heightening plate. After placing HDPE powder, reinforcement fibers are arranged in such way parallel

to lateral direction (120 mm), where another layer of powder is placed to cover reinforcement fibers to produce a regular composite thickness. There are double heating system and thermocouple sensor to monitor and control temperature keeping it at 130 °C for 10 minutes to ensure no powder particle left unmelted, which will eventually achieve the best matrix- enforcement adhesion. The produced specimens have been reinforced with CF and Kevlar at fibers content of 0.5, 1, 1.5, 2 vol. %.

Table 3 mechanical properties of Kevlar provided from supplier.

Property	Value
Tensile Strength (MPa)	3600-4100
Tensile modulus (GPa)	131
Density (g/cm3)	1.44

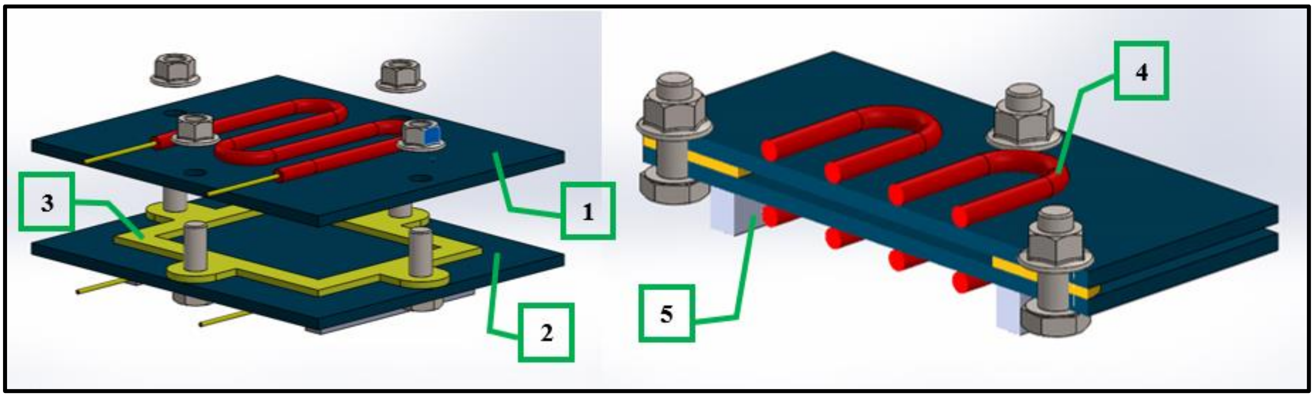

Fig. 2. The arrangement of the die, (1) Upper plat, (2) Lower plate, (3) Spacer, (4) Heater, (5) Base support.

Reciprocating wear test were selected to simulate the motion generated from cervical spine section. Cervical fusion specimens were adhered to the table, while a cylindrical pin made of bone (8 mm in diameter) is held by chuck as shown in Fig 3. The test has been conducted at 250 strokes per minute with four normal forces (8, 10, 12, 14 N) for time duration of 5 minutes for each test. Load cell is connected through Arduino circuit and load cell amplifier to record the values of friction force. The testing conditions are shown in Table 4.

Table 4 Testing parameters.

parameter	value
Matrix	polyethylene
Reinforcement	Carbon Fiber, Kevlar Fiber
Volume Fraction (V_F) (%)	(0.5, 1, 1.5, 2)
Reciprocate Velocity (Strokes per minute)	250
Normal Force (N)	8, 10, 12, 14
Condition of sliding	Dry

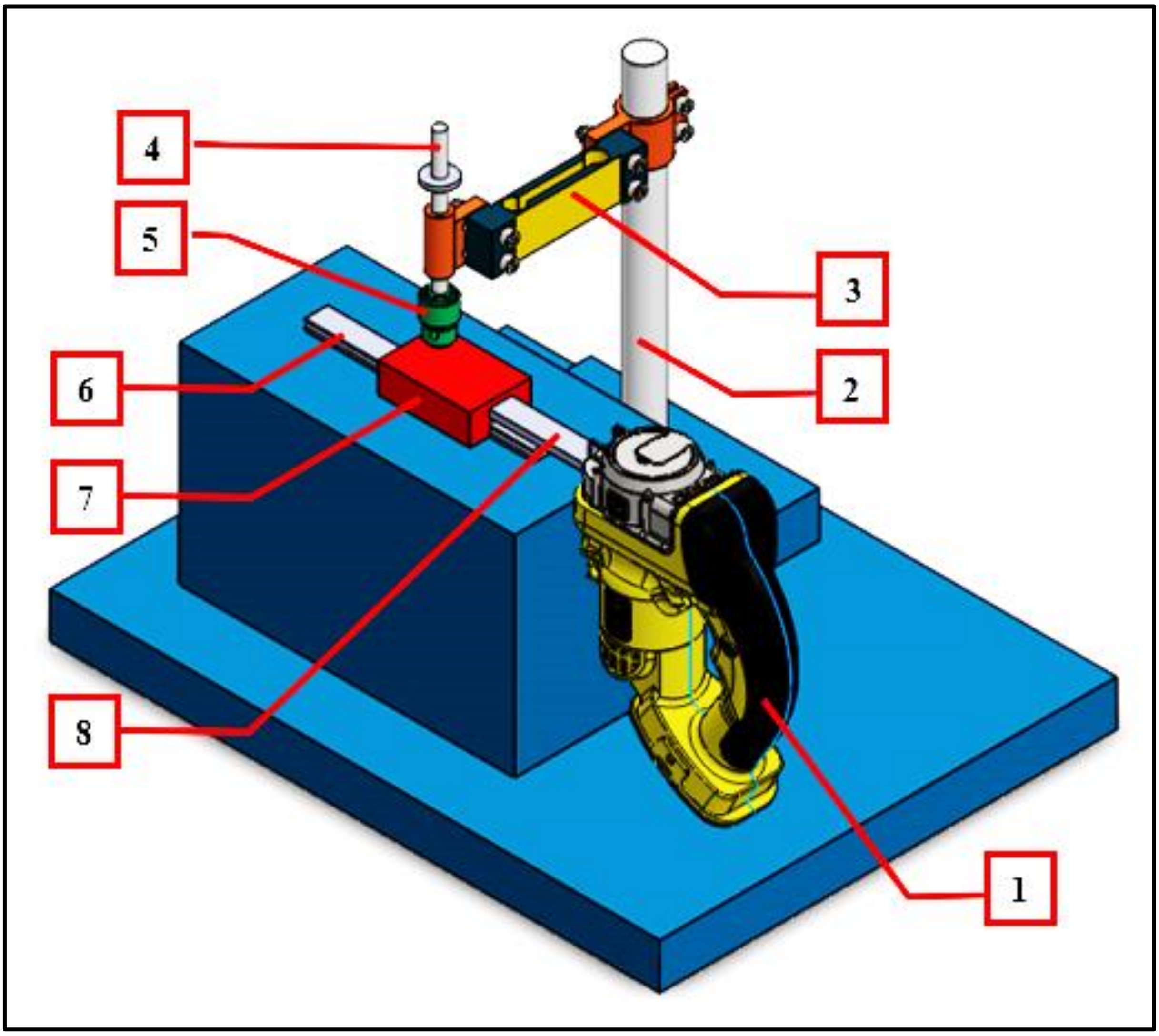

Fig 3. Reciprocating friction and wear test machine. (1) Reciprocating device, (2) Column, (3) Load cell, (4) Weight holder, (5) Chuck. (6) Sliding guideway, (7) Table, (8) Reciprocating link.

RESULTS AND DISCUSSION

The effect of normal force and fiber content on wear at different volume fraction for both CF and Kevlar has been examined to determine the dominant wear mechanism. Figures 4 - 7 illustrate the effect of increasing the load and fibers content on wear of the tested composites. It can be noted that specimens free of reinforcing fibers have relatively higher values of wear compared to composites reinforced by CF or KF. As the volume content of the tested fibers increased, wear decreased.

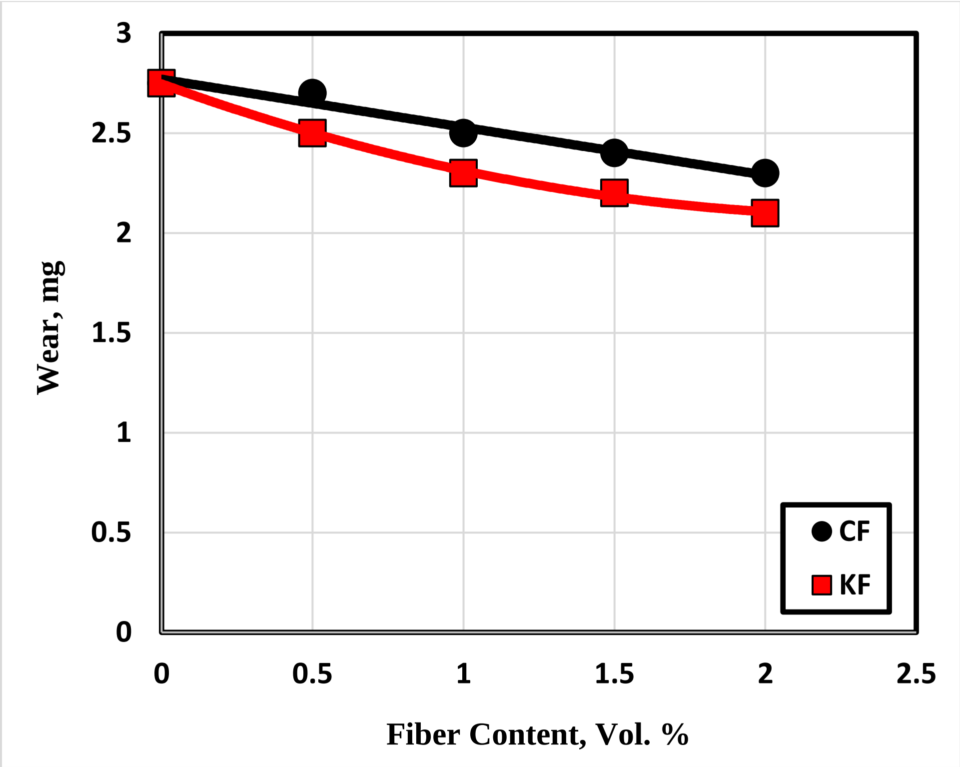

Fig. 4 Wear displayed by the tested composites at 8 N.

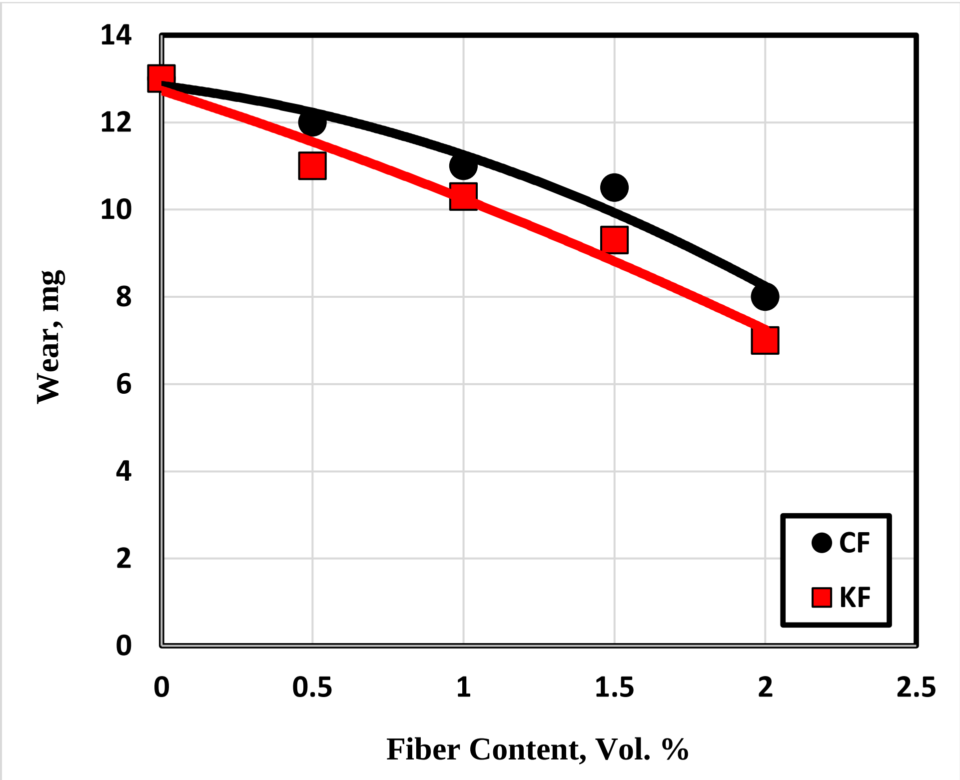

Fig. 5 Wear displayed by the tested composites at 10 N.

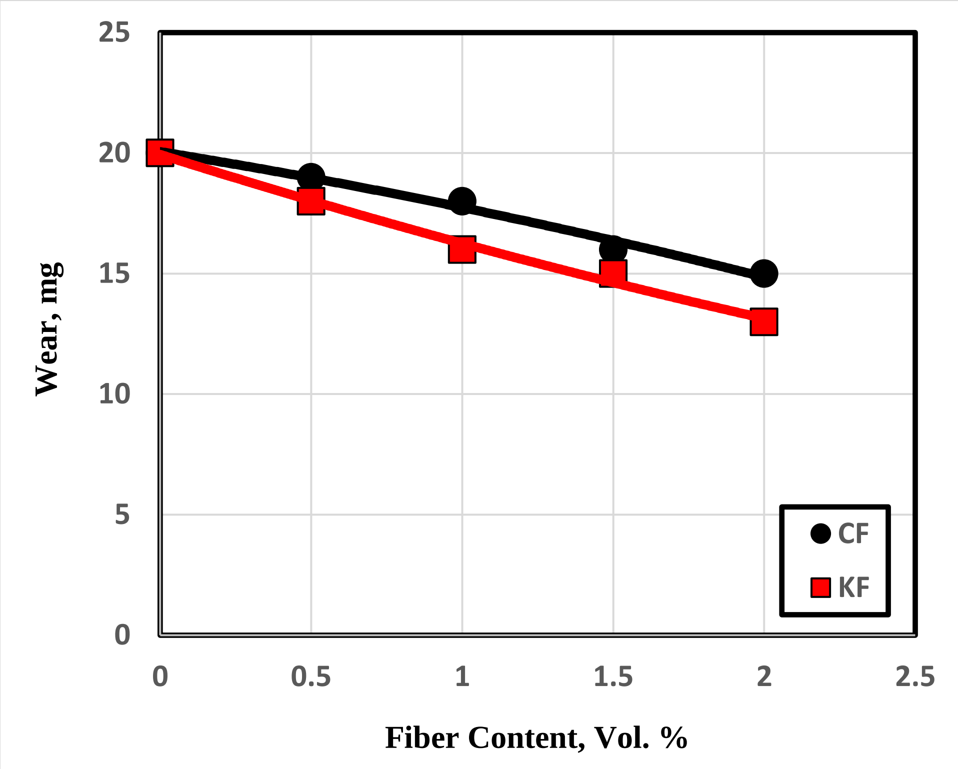

Fig. 6 Wear displayed by the tested composites at 12 N.

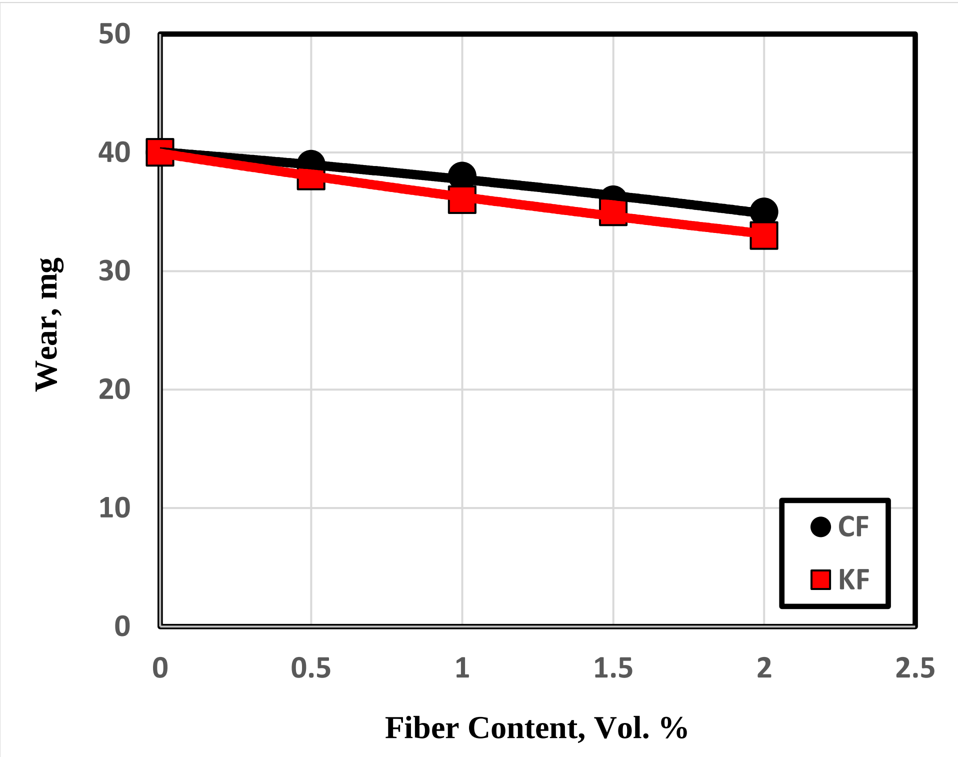

Fig. 7 Wear displayed by the tested composites at 14 N.

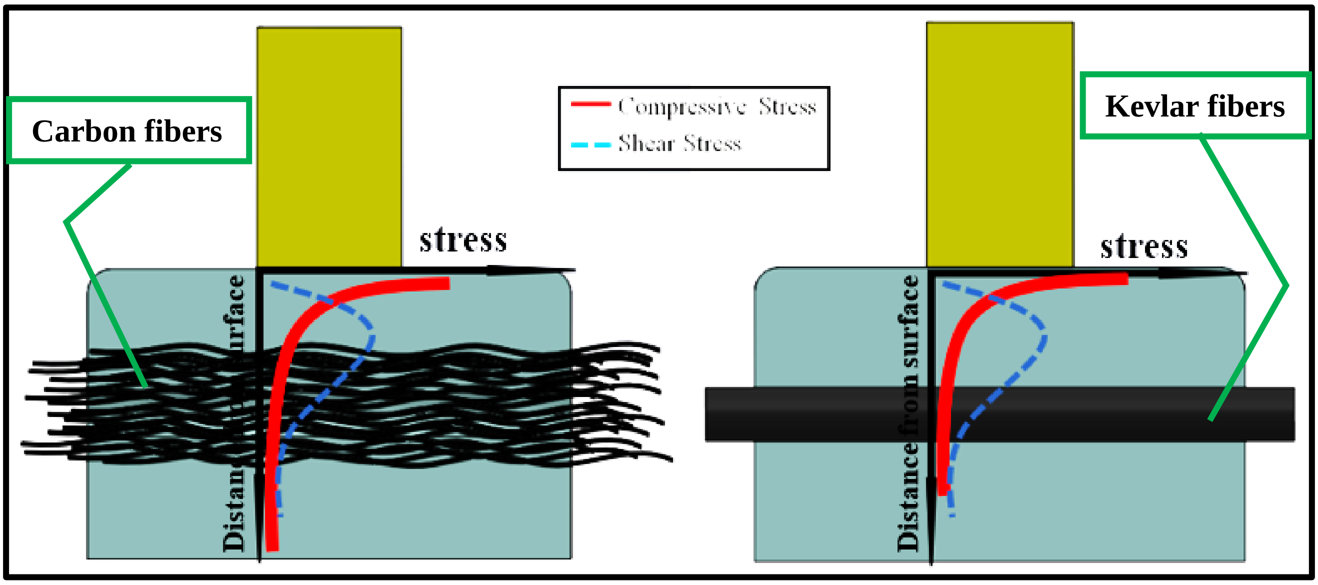

Fig. 8 Stress distribution during abrasion of HDPE reinforced by the tested fibers.

For further understanding, the effect of increasing fibers content is shown at different values of applied load. It was found that KF has reduced wear values compared to CF. However, the tested fibers displayed improved performance. KF experienced relatively lower wear values that that displayed by CF. The cause of this phenomenon is attributed to the wear governing mechanism shown in Fig. 8. Compressive and tenslie stresses are produced by the sliding of the bone on the surface of the tested composites. Due to the deformation of the HDPE due to the abrasion of the bone pin, the produced stresses in front of the pin are compressive, while that are behind the pin are tensile stresses. On the other hand, the stresses formed by friction forces and dragging of the HDPE are mostly tensile and shear, [25, 26]. Kevlar fibers are compact in nature and occupy less space compared with wrinkly and curling CF that means filling larger space inside the matrix.
Fiber content of 2.0 vol. % exhibited an improvement in terms of wear because the fibers are located near maximum shear zone which will involve fibers to help distribute stress between matrix and reinforcement more efficiently.

CONCLUSIONS

1. Polyethylene composites free of reinforcing fibers represented relatively higher wear values compared to composites reinforced by CF or KF. As the volume content of the tested fibers increased, wear decreased.
2. Kevlar fibers reinforcing polyethylene offered lower wear values than that caused by composites reinforced by carbon fibers.
3. Improvement in wear may be attributed to the strengthening effect of the tested fibers, where they withstand the shear and tensile stresses inside the matrix of the composites.

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