*International Journal of Application or Innovation in Engineering & Management (IJAIEM)*
**Web Site: www.ijaiem.org Email: editor@ijaiem.org**
**Volume 4, Issue 2, February 2015 ISSN 2319 - 4847**

# Improve Flexural Strength of PMMA/SR Polymer Blend by Reinforcement with Carbon Fibers as Prosthetic Foot Polymer Material

**Ahmed NamahHadi [1], JawadKadhimOleiwi [2]**

[1]University of Misan / College of Sciences,Misan City / Iraq

[2]University of Technology / Materials Engineering Department, Baghdad City/ Iraq

## ABSTRACT

***Prosthetic Foots or artificial limbs, are fabricated devices that provide amputees with a replacement for their missing limb, restoring some function , The development of polymer blend materials has, in recent years, led to technological advances across a wide range of applications in modern orthopedic medicine and prosthetic devices , In this study poly methyl methacrylate (PMMA) / silicone rubber ( SR ) reinforcement by carbon fiber ( CF ) blends has been developed as prosthetic foot materialby improved flexural properties as suitable polymer blend material for this application. Polymer blends (PMMA:SR) 90:10 ; 80:20 ; 70:30 ; 60:40 ; 50:50 were prepared reinforcements each one by carbon fibers from 5-15% ( CF ) the reinforcement material was short length and randomly , then flexural test was carried out for prepared specimens , and effect of reinforcement by carbon fibers on flexural strength of polymer blends were determined . From the results showed that the flexural strength, flexural modulus of five polymer blends was increased as reinforcement material increased and improved as best comparative prosthetic foot material.***

**Keywords :** Poly Methyl Mehta Acrylate ( PMMA ) , Silicone Rubber ( SR ) , Carbon Fibers ( CF )

## 1. INTRODUCTION

Prosthetic foot Options which attempt to restore their natural gait patterns and Ankle range of motion. Such foot options are chosen based on their daily activities, occupational demands and personal parameters such as age and weight Popular prosthetic feet on the market include dynamic response feet, such as Flex Foot, which currently allow for the most natural gait and multi-axis feet which have six degrees of rotation at the ankle joint . However, such prosthetic foot designs lack the flexibility necessary for amputees to perform activities such as kneeling and putting on shoes, which imparts limitations on the user. This problem is the basis for the development of a more functional prosthetic foot. The proposed design must have increased flexibility to facilitate kneeling, while maintaining or enhancing the normal gait patterns that are created by current, top of the line prosthetics. The foot must also provide stability and balance to the amputee [1,2].

Initial material made of wood and metals for artificial legs had major drawbacks, since they were limited by their weight, and had poor durability to corrosion and moisture induced swelling , These limitations resulted in restricting the user to slow and non-strenuous activities due to poor elastic response during stance ,Due to these limitations, polymer composites were introduced for material of choice for limb systems, because of their "lightweight, corrosion resistance, fatigue resistance, aesthetics, and ease of fabrication" , Polymer composites can be either thermosetting or thermoplastics composites that are reinforced with glass, carbon, or Kevlar fibers [3].

During the past 10 years the most notable reinforcing materials for orthopedic use have been carbon fibers. Especially for lower limb prosthesis carbon composite lay-ups are very popular. These composites are chosen or their flexibility and energy storage and release properties. The fibers can be fabricated in different ways such as being braided, woven, knitted, or laminated. According to a lower limb design by Strike &Hillery, the lamination would allow them to have specific tensile strength and stiffness "by changing the resin and controlling the angles between successive layers [4.5].

Applications of polymer are being developed in such diverse areas as conducting and storage of electricity, heat and light. Indeed, polymers have played and will continue to play an increasingly important role in all aspects of life. In recent years mixed systems or blends of different polymers have been developed which are of increasing importance in the plastic industry [6] .

A polymer blend or polymer mixture is a member of a class of materials in which two or more polymers are blended together to create a new material with different physical properties. They combine in an advantageous manner the properties of the alloying components and in some cases the properties of the blend are superior to those of the individual components, Blending of polymer is a technological way for providing materials with full set of desired specific properties at the lowest cost, e.g. a combination of strength and toughness, strength and solvent resistance, etc.

Blending also benefits the manufacturer by offering improved process ability, product uniformity, quick formulation changes, plant flexibility and high productivity, i.e. polymer blending is one of the most common techniques employed for developing new polymeric materials [7, 8] .

PMMA and SR were used as polymer blends for this research as suitable material for prosthetic foot,PMMA is a linear thermoplastic polymer. PMA has a lack of methyl groups on the backbone carbon chain its long polymer chains are thinner and smoother and can slide past each other more easily, PMMA has high mechanical strength, high Young's modulus and low elongation at break ,Table 1 some of mechanical characteristics of PMMA , SR are general Category of synesthetic polymers whose backbone is made of repeating silicon to oxygen bonds. In addition to their links to oxygen to form the polymeric chain, the silicon atoms are also bonded to organic groups, typically methyl groups, SR is generally no reactive, stable, and resistant to extreme environments as show from Table2 properties of silicon rubber cold cure [9, 10].

**Table 1** Mechanical characteristics of polymers [9].

| Material | Specific Gravity | Tensile Modulus GPa | Tensile Strength MPa | Yield Strength MPa | Elongation at break % |
|---|---|---|---|---|---|
| Polyethylene (low density) | 0.917–0.932 | 0.17–0.28 | 8.3–31.4 | 9.0–14.5 | 100–650 |
| Polyethylene (high density) | 0.952–0.965 | 1.06–1.09 | 22.1–31.0 | 26.2–33.1 | 10–1200 |
| Poly(vinyl chloride) | 1.30–1.58 | 2.4–4.1 | 40.7–51.7 | 40.7–44.8 | 40–80 |
| Polytetrafluoroethylene | 2.14–2.20 | 0.40–0.55 | 20.7–34.5 | ------ | 200–400 |
| Polypropylene | 0.90–0.91 | 1.14–1.55 | 31–41.4 | 31.0–37.2 | 100–600 |
| Polystyrene | 1.04–1.05 | 2.28–3.28 | 35.9–51.7 | ------ | 1.2–2.5 |
| Poly(methyl methacrylate) | 1.17–1.20 | 2.24–3.24 | 48.3–72.4 | 53.8–73.1 | 2.0–5.5 |
| Phenol-formaldehyde | 1.24–1.32 | 2.76–4.83 | 34.5–62.1 | ------ | 1.5–2.0 |
| Nylon 6,6 | 1.13–1.15 | 1.58–3.80 | 75.9–94.5 | 44.8–82.8 | 15–300 |
| Polyester (PET) | 1.29–1.40 | 2.8–4.1 | 48.3–72.4 | 59.3 | 30–300 |
| Polycarbonate | 1.20 | 2.38 | 62.8–72.4 | 62.1 | 110–150 |

**Table2** Properties of silicon rubber [6].

| Mechanical Properties | Value |
|---|---|
| Appearance | white |
| Hardness, Shore A | 30±2 |
| Tensile Strength, Ultimate | 5.8 MPa |
| Elongation at Break% | 420 |
| Tear Strength ($kgf/cm^2$) | 30 |
| Curing time/mentis | 2-6 |
| Mixing proportion of curing agent (%) | 2-4 |
| Density ( $g/cm^3$) | 1.08 |

The aim of this work majority of prosthetic foot failure as show from (Fig..1) ( specialized in the fore foot region ), As show from figure 1 the mostly failure in prosthetic foot , Two polymer PMMA:SR reinforcement by CF was used as improvement polymer materials for this application ( Prosthetic Foot ) , with improved one of the important mechanical properties Flexural strength by reinforcement with sort carbon fibers , that mean increase absorption energy by two ways one by added rubber to PMMA and other by reinforcement by short carbon fibers CF to support this property for this application .

**Fig. 2** Failure of prosthetic Foot [11].

## 2.EXPERIMENTAL WORK

PMMA polymer was supply from Italian BMS S.R.I. Company for dental Materials as polymer and hardener self-curing, silicone rubber (silicon) and silicon are generally named as two-part room temperature sulfurated silicone rubber, which features an exceptional fluidity and good operability When mixed with 2□□4□ curing agent, they can still be operable within 35 minutes, but it will be formed after 3-5 hours supply from Shenzhen Hong Ye Jie Technology Co., LTD., Carbon Fiber CF is used as reinforcement material , short carbon fiber with length 3mm reinforcement polymer blends from 5-15% CF , As show from Table 3 , Three polymer blends prepared by PMMA:SR ( 90:10 , 80:20 , 70:30 ; 60:40 ; 50:50 ) all three polymer blends reinforcement by CF from 5-15% and the step for preparation this polymer blends :

Firstly PMMA polymer which is still in a liquid state to SR which in a liquid state and mixed well by using mechanical mixer to form a binary blend then reinforcement by Carbon Fiber ( CF ) added to the binary blend to form a composite polymer sheet , Secondly Pouring the blend into the mould , Casting sheet was left inside the mould at room temperature about (15-20 min. ) for both blends , Finally solidification the testing samples were obtained by cutting the cast sheets according to the relevant ASTM standard All properties were measured at room temperature (25-30)°C.

A 3-point bending test device was used to determine the flexural strengths and flexural moduli. The device consisted of a loading wedge and a pair of adjustable supporting wedges placed 50 mm apart. The specimens were centered on the supporting wedges and the loading wedge was set to travel at a crosshead speed of 5 mm/min engaged at the center of the upper surface of the specimens. Specimens were loaded until fracture occurred. Transverse strengths were calculated using the following equation;

$$S = 3PI / 2bd^2$$

Where:S = transverse strength (N/mm2), P = load at fracture (N), I = distance between the supporting wedges (mm), b = width of the specimen (mm), and d = thickness of the specimen (mm).

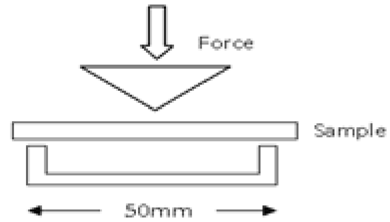


**Fig.2** Schematic illustration of flexural strength test arrangement

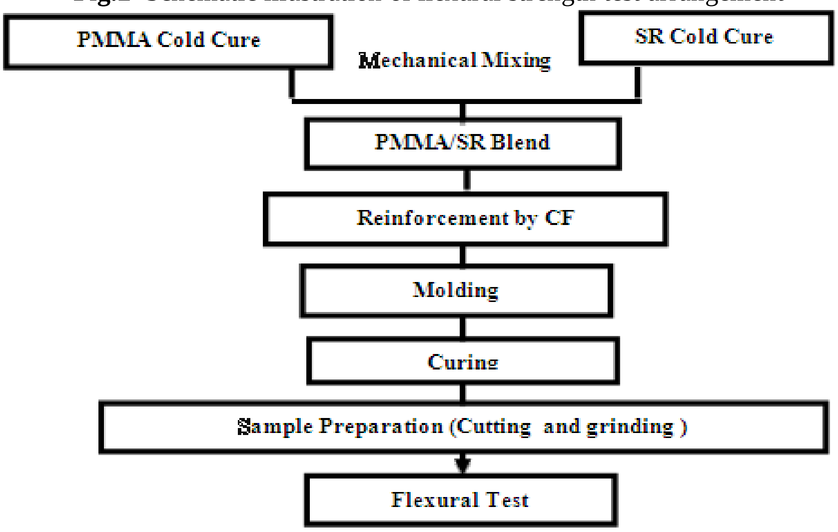


**Fig.3** Flowchart of experimental work ( General Steps )

## 3.RESULTS AND DISCUSSION

The flexural properties of acrylic resins after breaking were generally improved when fibers were added but their strength was dependent on the position of the fiber inside the sample. An increase in the flexural strength is possible if the fibers are placed in opposite direction to the breaking force [12].

Flexural strength and Flexural Modulus results in Table 3 . as mentioned below cods and results for all polymer blends prepared , As shown in Fig.4Effect CF on the flexural strength of PMMA/SR polymer blends , and Fig.5Effect CF on the Flexural Modulus of PMMA/SR polymer blends , Flexural strength and Flexural Modulus will be raised as reinforcement material CF% increase from 5-15 % due to the higherbonding between polymer blends and CF and strong adhesion of polymer matrix material to the reinforcement materials will improve the good stiffness of polymer chain thus produce good strength for all polymer material with reinforcement .

**Table3** Samples Codes , Results of Flexural Strength and Flexural Modulus for PMMA:SR polymer blends

| Sample Code | PMMA: SR | CF% | Flexural Strength MPa | Flexural Modulus GPa |
|---|---|---|---|---|
| 1-A | 90:10 | 0 | 71.85 | 2.23 |
| 2-A | 90:10 | 5 | 75.44 | 2.34 |
| 3-A | 90:10 | 10 | 81.32 | 2.52 |
| 4-A | 90:10 | 15 | 87.70 | 2.72 |
| 1-B | 80:20 | 0 | 69.22 | 2.14 |
| 2-B | 80:20 | 5 | 74.70 | 2.31 |
| 3-B | 80:20 | 10 | 79.00 | 2.45 |
| 4-B | 80:20 | 15 | 85.60 | 2.65 |
| 1-C | 70:30 | 0 | 66.44 | 2.06 |
| 2-C | 70:30 | 5 | 71.10 | 2.20 |
| 3-C | 70:30 | 10 | 77.54 | 2.40 |
| 4-C | 70:30 | 15 | 80.75 | 2.50 |
| 1-D | 60:60 | 0 | 60.30 | 1.87 |
| 2-D | 60:60 | 5 | 64.80 | 2.01 |
| 3-D | 60:60 | 10 | 69.40 | 2.15 |
| 3-D | 60:60 | 15 | 72.00 | 2.23 |
| 1-E | 50:50 | 0 | 52.55 | 1.63 |
| 2-E | 50:50 | 5 | 56.90 | 1.73 |
| 3-E | 50:50 | 10 | 61.25 | 1.90 |
| 4-E | 50:50 | 15 | 64.50 | 2.00 |

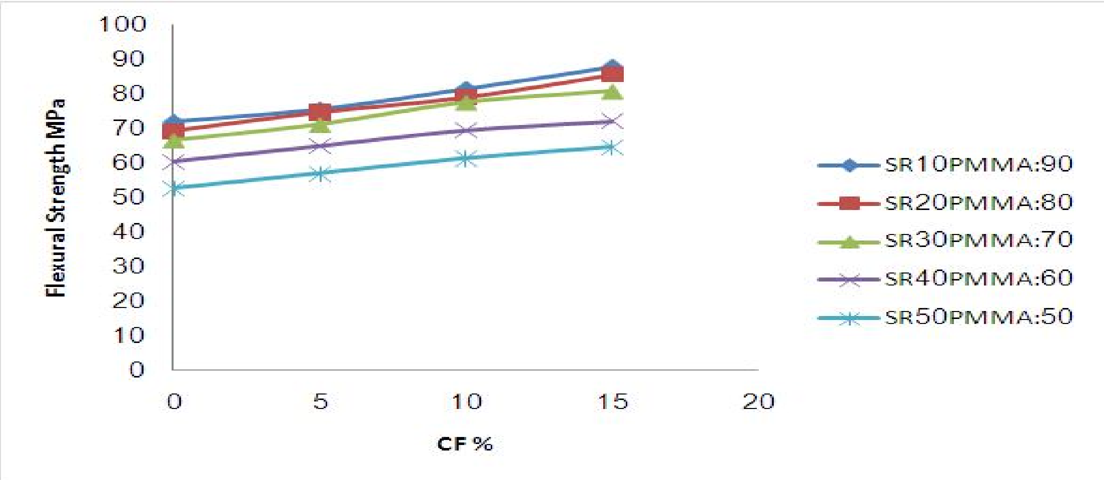


**Fig.4** Effect CF on the Flexural Strength PMMA:SR Polymer Blends

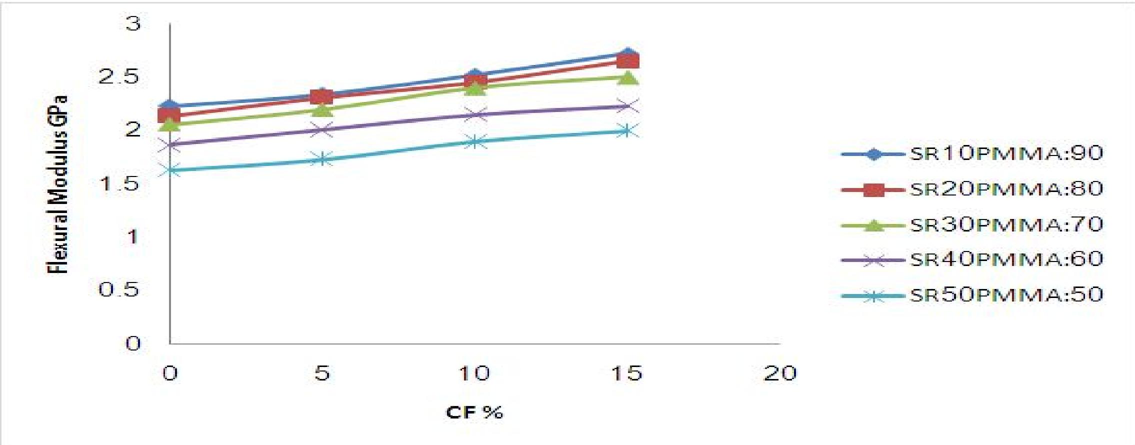


**Fig.5** Effect CF on the Flexural Modulusof PMMA:SR Polymer Blends

## 4.CONCLUSION

Experiments were performed in order to improve the Flexuralstrength , Flexural Modulus properties for polymer blends as prosthetic foot material by reinforcement with short carbon fibers , this improvement as follows:

- Flexuralstrength, Flexural Modulus increase as reinforcement material increase from 5-15% CF.
- Improve the Flexural strength support dorsiflexion of polymer materials used for prosthetic foot application.
- Improve Flexural Strength for 90PMMA/10SR reinforcement by 15%CF with approximately 16%, Improve Flexural Strength 80PMMA/20SR reinforcement by 15% CF with approximately 17%, Improve Flexural Strength 70 PMMA/30SR reinforcement by 15% CF with approximately 15%.
- Improve the flexural strength by reinforcement with short carbon fiber ( CF ) will enhancement this application by lower cost polymers used with cold cure simple for molding it's very important for Prosthetic foot application .

**Acknowledgments**

Authors are most grateful to Mr. JawadKadhimOleiwi , for their motivation and support throughout the study. Also acknowledge and thankful to the participants who involved in the study.

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