MATERIALS ENGINEERING | RESEARCH ARTICLE

Mechanical properties of Carbon-matrix composites for a blade runner’s artificial leg

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Abstract: The use of fiber-reinforced polymer (FRP) for prosthetic devices is now very common. Various polymer resins have been reinforced the fiber yielding composite with better strength-to-weight characteristics compared to a single material and also providing better biocompatibility. The purpose of the present study was to examine a single glass, carbon fiber with various matrix combinations for a composite of a blade runner’s artificial leg. The polymer matrices, namely epoxy bakelite (ER), casting (CR), orthocryl (OR), and polyester (PR) resins were selected, while evaluations of mechanical and physical properties of composite samples...
including tensile and bending, impact, hardness, and density were performed. Results showed that the combination of the fiber-orthocryl resin provided the best composite with the highest average tensile strength (483.94 MPa). Similarly, the highest average bending stress could be manufactured by combining fiber and orthocryl resin (494.17 MPa), but having the lowest average value of impact energy (5.6 J). The highest average hardness value could be provided by carbon—polyester (PR) combination (21.10 VHN), while the high specific strength of the composite could be achieved by the OR composite. The combination of carbon fiber and epoxy matrices is potential for use for a blade runner’s artificial leg because of having a better energy absorption on impact load. The outcome of the study may also assist as a reference for future work in the area of prosthetic material.

Subjects: Mechanical Engineering; Testing; Manufacturing Engineering; Biomedical Engineering; Materials Science; Design

Keywords: Fiber-reinforced polymer; Mechanical Testings; Various Resin; Blade runner’s artificial leg

1. Introduction

Recently, advanced material technologies have been developed widely in the healthcare industry through demanding smart and novel materials for the prosthetic leg system, which has a good mechanical property and long durability. Here polymers are commonly employed as biomedical materials instead of metals and ceramics because of their characteristics such as lightweight and good formability, stiffness, and relatively inexpensive material (Anggoro et al., 2017; Wang, 2003). Additionally, they resist corrosion. Nevertheless, the use of polymer components for biomedical materials is subject to constraining properties, such as lack of thermal and chemical stability with acid and environmental stability against UV, and poor heat and electrical conductivity (Hsieh et al., 2010). Accordingly, polymer composites require filler materials (i.e., particles, fibers, or platelets, synthetic or natural, organic or inorganic) at any scale (macro, micro, or nano) for the matrix reinforcement (Almeida et al., 2013; Andrew et al., 2019; Egan & Drake, 1989; Manjunatha et al., 2009). Particularly, the properties of composite products depend on the characteristics of their filler and the matrix materials.

Further, the mechanical property of polymers can degrade over time when they are exposed to UV, high temperature, pH, and humidity (Bibo et al., 1995, 1994). Correspondingly, various fibers were proposed for reinforcing the host matrix of polymer to improve the mechanical property of composites. Specifically, the requirements of fibers for matrix reinforcement should meet a good length-to-width ratio, environmental stability, uniformity, and flexibility. Additionally, the fibers can protect against unfavorable environmental conditions and maintain their place throughout the matrix (Bhagwat et al., 2017). Practically, fiber-reinforced polymers (FRP) are designed for replacing naturally biomedical materials.

At present, there are varying fibers proposed for reinforcing polymer matrix yielding the FRP composites with improved mechanical strength (Kumar et al., 2017). In particular for medical applications such as dental and prosthetic products, there is a great concern for biomedical applications using more than one filler material to contribute to the mechanical performance of composites (Panthapulakkal & Sain, 2007; Pegoretti et al., 2004). Here the development of dental and prosthetic products mainly focuses on tremendous stiffness and strength improvement. However, other property concerns in the areas of composites for prosthetic leg design may include compatibility with a living system, surface roughness, and imitating natural biomedical structure (Petrucci et al., 2013).
Further design of the blade runner’s artificial leg requires a theoretical understanding of composites on material choice for the matrices and reinforcing fibers, mechanical property, and manufacturing techniques (Rajeshkumar et al., 2017; Vieille et al., 2014). Specifically, the mechanical property of the composite depends on characteristics of matrix and fiber size, and arrangement of the matrix and fibers, the interaction between the components. In this regard, the matrix phases in a composite material strongly influence the mechanical property of a composite. Therefore, intensive research on the mechanical properties of composites by various matrices with a single fiber is needed to provide a reference in the design of artificial legs. For these purposes, the present study is focused on carbon fiber-reinforced composites. The research method considered the matrix composition, fiber distribution, and way of fiber incorporation for the reinforcement.

In this present study, carbon fiber composite with fiber direction 0/90° was made on varying matrices of epoxy bakelite, resin casting, orthocryl, and polyethylene PMMA (Polymethyl methacrylate) matrices using the infusion resin method. Here, the most proper amount of resin to bring a blade runner’s artificial leg with carbon fiber composite was evaluated. Moreover, the designed composite with a variety of matrices was then examined by tensile, impact, bending, hardness testing, respectively, while density and porosity were examined. The study is expected to provide a practical insight into the effects of varying matrices on the mechanical properties of FRP composite for the blade runner’s artificial leg.

2. Materials and method

2.1. Fibers, matrix, and hardener used in the study

Materials used in the composites included a carbon fiber woven twill 2 × 2. This carbon fiber has a thickness of 0.25 mm. For the flexure test specimen, the carbon fiber was then cut to become 13 layers with ± 3.2 mm thickness according to the ASTM standard, while specimens of 20 layers with a thickness of ± 5 mm were intended for tensile test and impact test specimen (Table 2.1). In the study, varying matrices in the form of resin reinforced with a carbon fiber were examined on their impacts on the mechanical and physical properties.

In the study, the resin was selected for FRP composites including polymethyl methacrylate (PMMA)-orthocryl, epoxy chlorohydin bisphenol (Bakelite® EPR 174), epoxy resin, and unsaturated polyester resin (YUKALAC® 1560 BL-EX). The hardener used as a mixture of Bakelite® EPR 174 resin is the curing agent Bakelite® EPH 555. This hardener has very low viscosity, light color, and room temperature humidity for liquid and solid epoxy. Similarly, the epoxy resin was selected for substrates because of its excellent properties for hygroscopicity, corrosion resistance, versatility, and durability. Subsequently, the epoxy resin and hardener in the weight ratio of 2:1 were mixed in the matrix system and stirred manually for 20 min. Finally, the density of the composite product was determined by the Archimedes method.

| Table 2.1. Fiber Carbon (HDC-520-3 K) |
|--------------------------------------|
| Used Yarn                           | TR 30s-3 L          |
| Product Number                      | C520 3 K           |
| Weave                               | 2/2 Twill          |
| Carbon Thickness (mm)               | 0.25 ± 0.02        |
| Construction (thread count/inch)    |                     |
| Warp                                | 12.5 ± 1 Carbon 3 K|
| Weft                                | 13.5 ± 1 Carbon 3 K|
| Carbon Fabric Weight (g/M²)         | 204 ± 2            |
| Width (mm)                          | 1.500              |
2.2. Preparation of matrix composites
Specimens for mechanical testing were made by embedding the fiber on the polymer matrix. Before embedding the fiber within the matrix, the glass mat was lubricated by a gel to avoid binding the matrix material. Subsequently, the top and bottom surface of the glass was inserted by thin plastic sheets for yielding a good surface finish of composites. The matrix was mixed manually with the resin. Before arranging the layers, a wax was put onto the glass mat for easy transferring from the glass base when the composite hardened. All fabric layers with the carbon fiber were then arranged in a line in the same direction into the glass mat. Moreover, the carbon fiber was covered with peel ply, while inlet for the hose where the resin enters were placed before installing the sealant tape. Finally, the system was wrapped with a bagging film of the sealant tape. The infusion resin process was carried out by inserting the resin that has been stirred together with the hardener through the inlet of the reservoir part. At the same time, the vacuum pump was turned on during the infusion resin process until the resin was perfectly distributed. The specimens were cured for 24 h in the closed mold at room temperature. Finally, the specimens were removed from the mold and were tested according to ASTM standards (see Table 2.2).

2.3. Mechanical testing
The composites were mechanically tested, according to ASTM standards (tensile, flexural, impact, and hardness tests) (Table 2.2). Three specimens were examined for each testing and the values of mechanical properties of each composite were presented on average. Compositions of composite materials selected in the study are presented in Table 2.3.

2.4. Data analysis of variance and statistical test
In the present experiments, the mechanical property evaluation for three specimens subjected to tensile, flexural, and impact testing was considered. The mean and standard deviations of values of the mechanical properties were then presented. It is considered here that a statistical test was conducted for quantitative variables of mechanical properties (e.g., strength, impact, and micro-hardness). Accordingly, the mean was calculated to provide the interval and ratio levels of measurement. In the study, however, no univariate analysis of variance (ANOVA) test was performed to determine the differences among the four groups of samples.

3. Results and discussion

3.1. Tensile strength of composites
The superior tensile strength of the FRP composites is required for their utilization in biomedical applications. However, the heterogeneity of microstructures in fiber, interphase, and matrices makes tensile strength characteristics vary. In this study, carbon-reinforced in varying matrices provided the variation of the tensile strength in composites (Table 3.1). Considering the standard deviation, the tensile strength varied for all specimens, except the strength was almost constant in the RP specimen. Also, the composites showed a high standard deviation in general, probably since the low fiber content leads to resin-rich regions in the mats. However, samples with resin polyester (RP) resulted in better composite with lower standard deviation and higher strength, mainly for the resin polyester and the glass fiber composites. In particular, the use of casting resin for the matrix provided the CR

| Table 2.2. ASTM standards |
|---------------------------|
| Mechanical test | ASTM standard | Specimen size (mm$^3$) |
|------------------|----------------|-------------------------|
| Tensile          | ASTM-D638      | 183 x 19 x 5            |
| Flexural         | ASTM D790      | 56.0 x 12.55 x 3.25     |
| Impact           | ASTM D256-03   | 63.5 x 10.43 x 5.30     |
| Micro indentation | ASTM E384-99   | 25 x 25 x 3             |
### Table 2.3. Composition details of prepared fiber-reinforced composites

| Test Specimens | Number of layers | Resin Type               | Ratio resin to hardener/catalyst | Composition               |
|----------------|-----------------|--------------------------|---------------------------------|---------------------------|
| Tensile        | 20              | Casting resin (CR)       | 2 (resin): 1 (hardener)         | 100 ml | 50 ml |
|                |                 | Orthocryl resin (OR)     | 100 ml (resin): 1 teaspoon (hardener) | 146 ml | 2 teaspoons |
|                |                 | Resin Epoxy (RE)         | 1 (resin): 1 (hardener)         | 75 ml | 75 ml |
|                |                 | Resin polyester (RP)     | 100 ml (resin): 1 ml (catalyst) | 100 ml | 1 ml |
| Flexural       | 13              | Casting resin (CR)       | 2 (resin): 1 (hardener)         | 50 ml | 25 ml |
|                |                 | Orthocryl resin (OR)     | 100 ml (resin): 1 teaspoon (hardener) | 60 ml | ½ teaspoon |
|                |                 | Resin Epoxy (RE)         | 1 (resin): 1 (hardener)         | 30 ml | 30 ml |
|                |                 | Resin polyester (RP)     | 100 ml (resin): 1 ml (catalyst) | 60 ml | 0.5 ml |
| Impact         | 20              | Casting resin (CR)       | 2 (resin): 1 (hardener)         | 40 ml | 20 ml |
|                |                 | Orthocryl resin (OR)     | 100 ml (resin): 1 teaspoon (hardener) | 60 ml | ½ table teaspoon |
|                |                 | Resin Epoxy (RE)         | 1 (resin): 1 (hardener)         | 30 ml | 30 ml |
|                |                 | Resin polyester (RP)     | 100 ml (resin): 1 ml (catalyst) | 60 ml | 0.6 ml |

### Table 3.1. Tensile strength of the designed composites

| Resin Type               | Specimen | Tensile Strength (MPa) | Mean Tensile Strength (MPa) | Standard Deviation |
|--------------------------|----------|------------------------|----------------------------|--------------------|
| Casting resin (CR)       | 1        | 174.94                 | 236.54                     | 56.04              |
|                          | 2        | 284.50                 |                            |                    |
|                          | 3        | 250.17                 |                            |                    |
| Orthocryl resin (OR)     | 1        | 427.26                 | 483.94                     | 49.40              |
|                          | 2        | 506.62                 |                            |                    |
|                          | 3        | 517.93                 |                            |                    |
| Resin Epoxy (RE)         | 1        | 177.44                 | 306.34                     | 111.68             |
|                          | 2        | 367.44                 |                            |                    |
|                          | 3        | 374.14                 |                            |                    |
| Resin polyester (RP)     | 1        | 448.15                 | 453.61                     | 5.33               |
|                          | 2        | 458.80                 |                            |                    |
|                          | 3        | 453.88                 |                            |                    |
composite with the mean value of strength (236.54 MPa). In contrast, the strength of OR composite could be improved doubly when used a matrix of orthocryl resin. Additionally, the tensile strength of the composites could be improved by using epoxy and polyester resins as shown in RE and RP composites. This may be due to better adhesion of the glass fiber to the matrix (Bhagwat et al., 2017).

Further experiments provided the highest tensile strength of composite when used the orthocryl resin (OR composite of 483.94 MPa) during the study. Presumably, the carbon fiber plays a significant role in enforcing the orthocryl resin leading to improvement in the tensile strength of the composite. The mean value of strength was lower than that of carbon/epoxy composite previously reported in the literature (Babu Kiran & Harish, 2014). The cause of this significant difference value may relate to a defect found in some cases during manufacturing the specimen. However, the mean value of strength was still comparable to that of carbon/epoxy composite reported previously (Almeida et al., 2013). Specifically, carbon/epoxy composites could be made with a tensile strength of 700 MPa and a modulus of elasticity of 70 GPa along with its density of 1.6 g/cm3, in that the high specific strength of the composite is required for biomedical application.

Additionally, the quite high difference in tensile strength in the RE and RP composites (147.27 MPa) could be noticed, suggesting that the use of resin, polyester for the matrix yielded composite with significantly improved tensile strength. Although polyester resin has a good bonding agent, it may not bind better than epoxy resin. It is very common for polyester used in laminating resin of fiberglass or in a mold. In contrast to epoxy resin, polyester resin requires a catalyst (not hardener) for curing, thereby having a low shelf life because it can harden itself during storage. Moreover, the polyester resin can be set much faster than epoxy resin, but epoxy resins are more durable, more waterproof, better bonding agents, and longer life. Thus, this composite is suitable for blade runner's artificial leg. Accordingly, the epoxy resin is recommended to use as a matrix for the FRP composite of the artificial leg because of the better characteristic compared to polyester resin.

### 3.2. Flexural strength of the composite

The flexural strength could be used for evaluation of the matrix resin resisting, especially cavities under stress when subjected to tension and compression loads (Eronat et al., 2009; Manhart et al., 2000). Specifically, tensile, compressive, and shear stresses acted simultaneously on specimens during flexural testing. The measured flexural strength of various composites indicated that the flexural strength depends upon varying resin materials (Table 3.2). In general, the composites

| Table 3.2 Flexural strength of the designed composites |
|---------------------------------------------------------|
| **Resin Type** | **Specimen** | **Flexural Strength (MPa)** | **Mean Flexural Strength (MPa)** | **Standard Deviation** |
|---------------|-------------|-----------------------------|-------------------------------|----------------------|
| Casting resin (CR) | 1 | 120.40 | 115.53 | 27.69 |
| | 2 | 140.47 | | |
| | 3 | 85.73 | | |
| Orthocryl resin (OR) | 1 | 500.22 | 494.17 | 45.55 |
| | 2 | 445.90 | | |
| | 3 | 536.40 | | |
| Resin Epoxy (RE) | 1 | 493.90 | 446.94 | 79.57 |
| | 2 | 491.85 | | |
| | 3 | 355.06 | | |
| Resin polyester (RP) | 1 | 241.18 | 294.99 | 46.77 |
| | 2 | 325.96 | | |
| | 3 | 317.82 | | |
showed some fluctuations in strength that may relate to thickness variations in the samples. Also, the values of flexural strength for all composites have a high standard deviation.

Similar to the tensile strength of composites, the highest flexural strength could be achieved by the OR composite (494.17 MPa) as compared to those of all (CR, RE, and RP) composites. Presumably, the OR composite has a strong cavity resisting the compressive and tensile stresses. This finding relates to the interface condition between the orthocryl resin with carbon fiber (Eronat et al., 2009). Correspondingly, the flexural strength of the composite is much influenced by the interface state. When the strength of interfacial bonding is high and the load can pass upon effectively fiber and matrix, while the interfacial bonding is weak, making deflection for advancing crack thereby improving fracture toughness and preventing a catastrophic failure.

### 3.3. Impact loading of the designed composites

The absorbed impact energy of specimens was examined by the impact test with the Izod method. Correspondingly, the absorbed energy recorded in the impact test relates to the stored energy (energy-storing) on the composite. Here the stored energy in the form of elastic potential energy provides because of impact performance for runner foot prosthesis applications because the less energy absorbed, the more energy that can be reflected when running. Generally, the higher the impact energy could be absorbed, the greater impact resistance can have for running blades prosthetics when subjected to impact loadings.

**Table 3.3** presents values of the absorbed energy in impact tests on composites. Values of impact energy for all composites showed fluctuation with a low standard deviation. It was found that the use of casting resin in the CR composite provided the lowest impact value of 0.113 J/mm², while RE composite using epoxy resin yielded the highest impact value of 0.152 J/mm². This condition may be influenced by several factors, including the matrix choice and fiber architecture in the specimen. It was reported in the literature that the impact values for carbon fiber-reinforced composites with fiber direction 0/90 ° using epoxy resin could reach values in the range of 114.2 KJ/m² and 0.1142 J/mm² (Flášar, 2018). The carbon fiber/epoxy resin can absorb the high energy among other combinations of carbon fiber matrices, but resin variation did not give a significant difference on carbon fiber impact value result. This suggestion was confirmed by the previous assessment of Bibo et al. (1995), who proposed that the matrix has a minor influence on the impedance of carbon fiber against impact load (Morton & Godwin, 1989).

| Resin Type       | Specimen | Impact Value (J/mm²) | Average Impact Value (J/mm²) | Standard Deviation |
|------------------|----------|----------------------|-----------------------------|--------------------|
| Casting resin (CR) | 1        | 0.132                |                             | 0.113              |
|                  | 2        | 0.109                |                             | 0.117              |
|                  | 3        | 0.098                |                             |                    |
| Orthocryl resin (OR) | 1        | 0.136                |                             | 0.117              |
|                  | 2        | 0.138                |                             | 0.034              |
|                  | 3        | 0.136                |                             |                    |
| Resin Epoxy (RE) | 1        | 0.154                |                             | 0.152              |
|                  | 2        | 0.164                |                             | 0.012              |
|                  | 3        | 0.139                |                             |                    |
| Resin polyester (RP) | 1        | 0.166                |                             | 0.129              |
|                  | 2        | 0.078                |                             | 0.045              |
|                  | 3        | 0.143                |                             |                    |
Further comparative study of the impact performance of the FRP composites with different matrices and the same fiber had been addressed previously (Andrew et al., 2019). Specifically, the carbon fiber with poly (phenylene sulfide) and poly (ether ketone) matrices exhibited the distinctive impact performance on which composites with epoxy resin had experienced more extensive debonding, while a surface indentation was observed in poly (phenylene sulfide) with larger indent size than that in poly (ether ketone) composites (Vieille et al., 2014). Importantly, a tougher matrix provided a composite with better impact performance. Likewise, the carbon fiber-thermoplastic matrix experienced less damage.

By comparing with epoxy matrix-based counterparts, carbon fiber-thermoplastic composite showed a higher compression strength and less damage being associated with better impact resistance (Morton & Godwin, 1989). However, there is contradicting evidence of the influence of the thermoset matrix on impact resistance (Evci & Gülgeç, 2012; Safri et al., 2018). This confirmed that through a surface indentation, the thermoset composite has a lower indent size than that in thermoplastic composite implying that the thermoset composite has a high impact resistance (Bibo et al., 1995). Conversely, high-performance thermoplastics are frequently used as matrix composites mainly for damage tolerance purposes. These materials were considered to have more damage tolerant than thermoset-based composite materials (Andrew et al., 2019). Moreover, semi-crystalline thermoplastic resins present better characteristics (i.e. high degree of chemical resistance, excellent damage, and impact resistance) over conventional thermoset resins (such as epoxies). Specifically, the basalt fiber-thermoplastic composite could absorb the impact energy in the range of values (10 J and 20 J), while the higher impact energy (30 J) could be absorbed in an epoxy matrix composite.

3.4. Hardness
Hardness referring to the resistance of a composite to localized deformation was examined in the study. In this case, the deformation may happen as a result of indentation mode, bending, or cutting (Mohamed et al., 2018). In the composite system, hardness depends on the relative fiber volume and its modulus. Moreover, composite having low surface hardness value may relate to insufficient wear resistance and tendency to scratching, which can compromise fatigue strength and lead to failure of the composite under a compression load. For this reason, the use of fiber for reinforcement of the FRP composite was proposed in improving the hardness of the composite. In particular, fiber with a higher modulus of elasticity makes composite with good stiffness and high load holding capability. Additionally, fiber with the lower elasticity provides the hybrid composite with more resilient and more cost-effective.

Table 3.4 presents values of Vickers micro-hardness of composites with varying matrix materials. The lower the standard deviation of hardness value is shown for all composites. Moreover, a considerable increase in hardness could be observed in the RP composite, which has the highest value among those in other composites. The incorporation of resin, polyester made a remarkable increase in the values of Vickers micro-hardness for this preparation of composite. The designed FRP composite offers a candidate prosthetic material with better resilience, more cost-effectiveness, and wear resistance. Accordingly, the fiber-polyester composites are suitable for a runner blade with better resilience.

3.5. Specific strengths of composites
In general, the designed running-specific prostheses are focused on imitating a “running on toes” running blade with good stiffness, which depends on the runner’s body weight. The lightweight of FRP composite is concerned with the fabrication of the running blade relating to their highest specific strength and high specific strength. In this case, the specific strength of a composite was calculated from the ratio of strength and density. Table 3.5 presents the density and specific strength of the manufactured composites examined during the study, in which the carbon fiber-orthocryl resin matrix (OR) composite has a higher density and specific strength. The high specific strength of the OR composite may be attributed to the high-strength of the matrix and low-density
Table 3.4. Micro indentation hardness of the designed composites

| Resin Type     | Specimen | Vickers micro hardness (VHN) | Mean hardness Value (VHN) | Standard Deviation |
|----------------|----------|------------------------------|---------------------------|--------------------|
| Casting resin (CR) | 1        | 5.00                         | 5.07                      | 0.06               |
|                | 2        | 5.10                         |                           |                    |
|                | 3        | 5.10                         |                           |                    |
| Orthocryl resin (OR) | 1      | 4.60                         | 4.67                      | 0.06               |
|                | 2        | 4.70                         |                           |                    |
|                | 3        | 4.70                         |                           |                    |
| Resin Epoxy (RE) | 1        | 4.40                         | 4.40                      | 0.00               |
|                | 2        | 4.40                         |                           |                    |
|                | 3        | 4.40                         |                           |                    |
| Resin polyester (RP) | 1      | 20.70                        | 21.10                     | 0.34               |
|                | 2        | 21.30                        |                           |                    |
|                | 3        | 21.30                        |                           |                    |

Table 3.5. Specific strength of the prepared composites

| Composite | Mean Tensile strength (MPa) | Density (gr/cm³) | Specific strength (10⁶ cm) |
|-----------|-----------------------------|------------------|---------------------------|
| CR        | 236.54                      | 1.28             | 1.88                      |
| OR        | 483.94                      | 1.36             | 3.86                      |
| RE        | 306.34                      | 1.28             | 2.44                      |
| RP        | 453.61                      | 1.35             | 3.61                      |

of reinforcing fibers. Since the OR composite is strong, stiff, and light composites, it is a potential candidate for use a composite of the running blade. Moreover, high compressive strength and fracture toughness may contribute to the superior qualities of this material, in which available carbon/epoxy composites may easily produce a tensile strength of 700 MPa and a modulus of elasticity of 70 GPa in addition to its density of 1.6 g/ml (Scholz et al., 2011).

Given the present model of composite, the development of a specifically designed carbon fiber orthocryl resin matrix for sports prostheses provided lightweight material with great flexibility, but it has high strength (Scholz et al. (2011). This feature made the possibility of setting in an energy return system within lower-limb prostheses (Dyer et al., 2010; Nolan, 2008; South et al., 2010). Moreover, the use of the designed composite model allowed lower-limb amputees to actively participate in competitive sports. In addition to its mechanical properties and economical processing, the simple method for a runner blade composite could be applied independently using the experimental data collected during the study. However, a further design using CAD simulation or physical design needs to be done for providing a model of lower-limb prostheses that can be used for subsequent manufacturing of fiber-reinforced polymer (FRP) composites with superior strength.

In all, manual preparation of composites designed for the blade runner’s artificial leg was successfully presented and the mechanical properties presented a behavior close to the pure glass fiber composites (Scholz et al. (2011). Among the studied composites, the fiber-orthocryl resin matrix (OR) composite showed the highest overall performance. Also, the specific strength
highlighted the use of orthocryl resin matrix advantage, which can combine low density and high mechanical performance, being also more cost-effective for customized products in this case.

4. Conclusion
Fabrication of composites for runner blades with four (4) variations of resin, namely Epoxy Bakelite, Casting Resin, PMMA Orthocryl, and polyester using the infusion resin process has been successfully demonstrated in the study. By conducting several mechanical tests, results confirmed that the type of resin that has the highest average maximum stress was a variation of orthocryl PMMA (483.94 MPa). The highest average bending stress value was a variation of PMMA orthocryl which is 494.17 MPa. However, the smallest average value of absorbed impact energy could be obtained from the composite with casting resin variation of 0.113 J/mm². The highest average hardness value was a polyester variation of 21.10 VHN. Importantly, the designed composite with the highest specific strength could be attained from a variety of fiber and epoxy resin. Accordingly, more suitable for use in the blade runner’s artificial leg is proposed to select the orthocryl PMMA resin for the host matrix, because the resin has a maximum stress value and high bending stress. Also, this type of resin has a low value of impact energy.

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