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Characterization of synthetic fibers and cotton composites used in prosthetic socket

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Characterization of synthetic fibers and cotton composites used in prosthetic socket

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Abstract. This study aims to determine the bending and impact strength of the laminate composite Co/G/Co (cotton - glass fiber - cotton) and C/G/C (carbon fiber - glass fiber - carbon fiber) that are used by *Garuda Medica*, an orthotic and prosthetic manufacturer in Tridadi, Sleman Regency, to make prosthetic sockets. Co/G/Co and C/G/C laminate composites with layer variants of 2/1/2 and 4/2/4 for each composite were made by hand layup method. All variants were tested for their flexural and impact strength. The addition of the laminate layer and the replacement of the outer laminate increase the strength of the composite. The replacement of the outer laminate from cotton to carbon increased the strength. The lowest impact strength of the composites, namely the [Co_2/G/Co_2] variant, has met the requirement of the socket impact strength that is suitable for use. However, the stacking sequence of Co/G/Co and C/G/C are not recommended when viewed from the strength and classification of the constituent laminates.

1. Introduction

Persons with physical disabilities have limited mobility, which hinders their activities [1]. They can be assisted through rehabilitation program. Rehabilitation help to achieve and maintain optimal physical functions in interacting with the environment. This is done, among others, by preventing loss of function, slowing down the rate of loss of function, increasing or restoring function, compensating for lost functions, and maintaining existing functions [2].

One form of rehabilitation is the use of a prosthesis. Prosthesis is a component that resembles the shape of the body part, to replace the imperfect body part [3]. Meanwhile, WHO estimates that there are 100 million people who need prostheses and orthotics. However, in developing countries, including Indonesia, very few have access to these services. Among others, there are still very few prosthesis and orthotic providers [2]. *Garuda Medica* is an orthotic and prosthetic provider in Yogyakarta that produce various orthotic and prosthetic products, in which one of them is socket.

The socket is made from composite. Three reinforcement materials are used to make laminate composites namely cotton, fiber glass, and carbon fiber. All of them are in woven type. They use two types of composites with a composition of cotton-fiberglass-cotton (Co/G/Co) and carbon fiber-fiberglass-carbon fiber (C/G/C). The reason of those sequence is not known, except that according to them, carbon fiber is a strong and exclusive material. Products made of C/G/C composite are considered superior than those made of Co/G/Co composite, therefore they are more expensive. Sometimes they simply step on it to check the quality. The ideal socket should not just strong or expensive. It should be considered the optimal ratios of cost/benefit and strength/weight. The use of materials and manufacturing processes are carried out through the years of experience. However, material and product properties are not known. Material property data are very important for good prosthetic practice because they become a product standard. Therefore it can reduce product variation, material failures and material costs [4].

With the availability of data or specifications, producers and consumers can get more accurate information. The use of this information depends on the subject. Producer can equip their products with accurate and more convincing information. Producer can also use these specifications as a reference for developing their products, or to compare with other products. From the consumer's side, they can buy products with certain specifications, so they can make more convincing choices. Consumers can also use it to compare with other products. Based on the background, this research aims to characterize Co/G/Co and C/G/C composites with 2/1/2 and 4/2/4 layers sequence.

2. Methods

The test specimen was made by replicating the composite used *Garuda Medica*. It was difficult to replicate precisely because of the processes that were passed. The composition data were unavailable. In addition, production processes that involve cutting, removing excess material, and finishing also made the measurement of compositions difficult. For this reason, replication was only carried out by using the same material and layer sequence. The layers arrangement of 2/1/2 was the one used by *Garuda Medica*, while 2/4/2 was used to determine the effect of adding laminate on the strength of the composite.

2.1. Material

Lamination was constructed using fabric materials. They were glass fiber, carbon fiber, and cotton. Resin polyester was used as matrix. Release agent was used to coat the mold. Digital scale was used to weigh fibers and matrices. Measuring cups, pipettes and spatula were used to prepare the matrix. The composites were casted in a mold made of glass with dimensions of 180 mm x 180 mm x 20 mm. Saw and sandpaper were used to cut and finishing the composite into test specimens. In accordance with the tests and observations to be carried out, the test tools used were universal testing machine (UTM) and impact testing machine.

2.2. Procedure

The composites were prepared using hand lay up process. Resin was poured and the woven fabric were laid carefully to avoid air trapped. The composite was made with reinforcing arrangement of Cotton-Glass-Cotton (Co/G/Co) and Carbon-Glass-Carbon (C/G/C). Fibre cloths were overlaid in array of 2/1/2 and 4/2/4 for each composite. [Co_2/G/Co_2] means the composite has two layers of cotton, one layer of fiberglass, and two layers of cotton. So there are 4 varian of composites will be tested. Table 1 shows the composition of all variant.

Table 1. Composites specification.

Samples	Composition (wt.%)
[Co_2/G/Co_2]	Resin polyester (87.5) + Cotton (8.5) + *Glass fiber* (4)
[Co_4/G_2/Co_4]	Resin polyester (78) + Cotton (15) + *Glass fiber* (7)
[C_2/G/C_2]	Resin polyester (83.5) + Carbon (12) + *Glass fiber* (4.5)
[C_4/G_2/C_4]	Resin polyester (71.2) + Carbon (21.8) + *Glass fiber* (7)

After removed from the mold, the composite was visually examined to ensure that there was no defect. The edges were cut to removed excess resin and uneven part. The specimens were cut from the composites block. Then they were cleaned before tested.

The test from 4 specimens for each variant will be used. The tests performed were the flexural test using the three points bending method with reference to ASTM D 790 and the impact test using the Charpy method with reference to the ASTM D 256 standard. The tests were carried out at room temperature of 25 ° C.

3. Result

3.1. Flexural test
Figure 1 shows the average flexural strength for all composites. All treatment shows result in changes of flexural strength. Adding layer increases flexural strength of both Co/G/Co and C/G/C composites. In addition, altering the cotton layers with carbon layers also increases flexural strength.

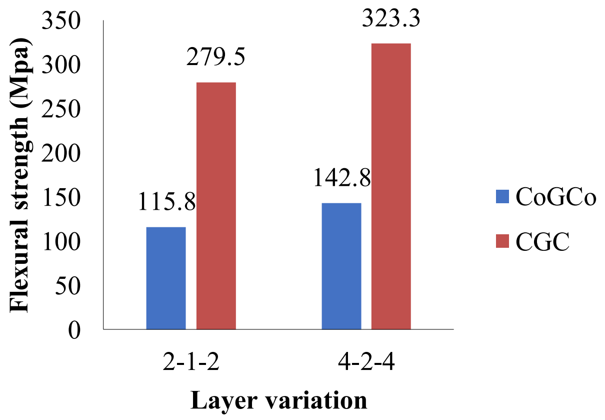

Figure 1. Flexural strength

3.2. Impact test
Figure 2 shows average impact strength of all composites. In all variants the impact strength of C/G/C composites is higher than Co/G/Co composites. The impact strength of the 4/2/4 variants are higher than that of the 2/1/2 variants, so that multiplying layer results in better impact resistance.

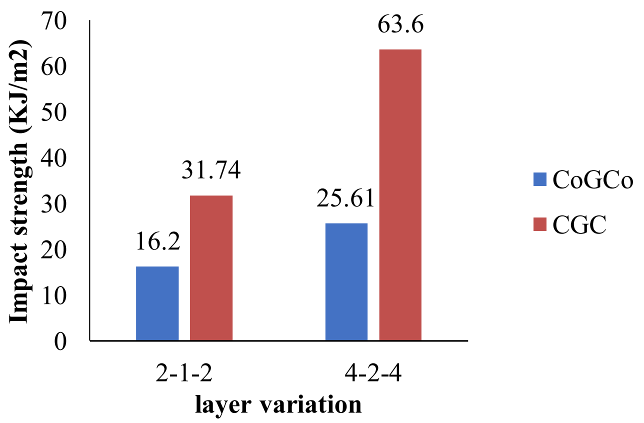

Figure 2. Impact strength

4. Discussion

4.1. Strength affected by layers combination
Altering outer layer and multiplying layers affect strength of composites. Altering cotton layers with carbon layer increases both flexural and impact strength significantly. Multiplying layers also increases both flexural and impact strength but in lower value. Figure 2 to 4 shows the increasing in percentage.

4.2. Outer layers effect on composites

Fiber affects the strength of the composite on its type, fraction, and orientation. The strength of carbon fiber is higher than that of glass fiber. The strength of glass fibers and carbon fibers are much higher than that of both synthetic and some natural fibers, such as corn fiber, cotton and bamboo [5]. Glass fiber can be up to 4 times higher, while carbon fiber is 8 times higher than that of others [4]. Carbon fiber also categorized as advanced composites material based on its strength to weight ratio [6]. Based on its strength there are 2 categories of material namely structural and filler. Medium strength fiber materials, such as glass fiber and high strength material such as carbon fiber are classified as structural materials. Meanwhile, low strength fiber materials, such as cotton is classified as fillers [4].

Table 2. Flexural strength increasing by multiplying laminat

2/1/2 to 4/2/4	
Co/G/Co	C/G/C
23%	16%

Table 3. Flexural strength increasing by alternate cotton with carbon fiber

Co/G/Co to C/G/C	
2/1/2	4/2/4
82%	126%

Table 4. Impact strength increasing by multiplying laminat

2/1/2 to 4/2/4	
Co/GCo	CGC
58%	100%

Table 5. Impact strength increasing by alternate cotton with carbon fiber

Co/G/Co to C/G/C	
2/1/2	4/2/4
96%	148%

Flexural and impact test show strength increase when cotton layer is altered by carbon fiber layer. These results are expected. Using high strength material in composit clearly yield in a strong composit. The flexural and impact strength increase almost 100% on 2/1/2 composites, and even higher on 4/2/4 composites.

While bended, the composites surfaces is divided into concave and convex parts. Between them, right in the middle layer is a neutral part. This part is considered unaffected by load. The convex part will experience tensile stress while the concave part will experience compression. The outer layer will bear maximum stress. Therefore, the layer position will also affect the strength of the composite.

It can be seen from the graphic in figure 1, that the bending strength of both C/G/C variants are much higher than that of Co/G/Co. It is clear since carbon is stronger than cotton. In the outer layer of the specimen that is subjected to tensile stress, carbon layer can withstand a greater load. When the cotton layer is in outer layer it will fail at lower load. The laminate arrangement with the stronger material (structural material) is on the outer layer makes the composite stronger, so the C/G/C laminate arrangement is preferred over the Co/G/Co arrangement.

The bending strength of the socket prosthesis serves to withstand the load due to the heavy force of the user which is supported by the socket. In addition, it must also be able to withstand dynamic movements when used for walking.

In Co/G/Co composite, in the middle layer, fiberglass, a stronger material than cotton, cannot support the integrity of composite since cotton layers in the surface already failure at lower load. Unlike Co/G/Co, C/G/C composite has carbon layer outside that works as structural material. As the load increases, the weaker layer of fiberglass in the middle layer remains safe. Carbon layers withstand the load until it fails. As the result, composite can withstand greater load.

4.3. Effect of multiplying layers on composite strength

When layers doubled while the fibers remain the same, the composites strength also increases. However, the increase is not as much as the increase caused by replacing outer layers with carbon. Flexural strength only increases 23% and 16% for Co/G/Co and C/G/C respectively. The impact strength experiences a higher increase, namely 58% for Co/G/Co and 100% for C/G/C.

Adding layers also means separating the outer layer further away from the middle layer. As the consequnce, the outer layer will recieve higher stress when composites bend. When the outer layer has low strength, the composite will fail faster. The strength increase is also not effective since it has to be compensated with very thick composites. Figure 3 shows that 4/2/4 arrangement of C/G/C composites is much stronger than that of Co/G/Co (323,3 Mpa to 142,8 Mpa). Therefore, putting high strength material far away from middle layer will be more advantageous.

4.4. Preference choice

When we look at the changes in the strength of the composite, the use of structural materials will have more significant impact than simply adding a layer of filler material. The addition of layers from 2-1-2 to 4-2-4 with the same material only increases the strength 23% for the Co/G/Co variant and 16% for the C/G/C variant. Meanwhile, replacing the outer layers with structural material, in this case cotton to carbon, increases the strength of the composite by 82% for the 2/1/2 variant and up to 126% for the 4/2/4 variant. This is also in accordance with other study [7], that placing carbon fiber away from the neutral axis and the low stiffness glass fiber at the neutral axis, and as the result, the flexural modulus is enhanced significantly.

On the other hand, according to Uzay [8] and Turla [9], carbon FRP composites have the lightest weight but the energy absorption capacity is the lowest because of its brittle behavior under impact load. Meanwhile Glass FRP composites are heavier but absorb impact energy greater than carbon FRP composites. Therefore, hybrid composites which also enhance the impact strength offer a better solution for the weight critical components.

If we compare the strength between [Co_2/G/Co_2] composite and [C_4/G_2/C_4] composite, the difference is huge. The difference comes from combination of two factors, namely, replacing cotton with carbon and multiplying layers. It can be said that the major factor is the replacement of cotton with carbon. However, multiplying layers gives minor effect.

The [Co_2/G/Co_2] composite has the lowest impact resistance among all variants, which is 16.2 KJ/m^2. However, this value is already higher than the composite impact resistance which is considered feasible when applied to the socket [10]. In its application, the prosthetic socket material needs to have a very good ability to the impact force. It provides safety when having the impact load from the rest of the leg.

Based on the strength and classification of fibers, the arrangement of the CoGCo and CGC variants is not appropriate. Since cotton is classified as a low strength material, it is more suitable as a filler material. In this case cotton should be put in the middle layer. In the CoGCo variant, the lower strength cotton is placed in outer layer which is more suitable for structural materials. Meanwhile, in the CGC variant, glass fiber which is classified as a structural material is in the middle layer which is more suitable for filling materials. Arrangements that include considerations of high strength and lower cost can be achieved by placing structural materials on the outside and fillers on the inside. In the CoGCo and CGC variants, cotton is a material that is more suitable as a filling material because it has the lowest strength and the cheapest price compared to glass fiber and carbon fiber [4].

5. Conclusion

The addition of the laminate layer and the replacement of the outer laminate increases the strength of the composite. The greatest enhancement effect results from changing the outer laminate of cotton to carbon. This is consistent with its classification as a structural material

The lowest strength of the composite, namely the [Co_2/G/Co_2] variant, has met the socket impact strength that is suitable for use, however, both the Co/G/Co and C/G/C variants are not proper layer arrangements when viewed from the strength and classification of the constituent laminates. The strongest laminate should be put in the outer layer and the weaker layer is inside as a filler material.

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