Experimental Study of Low Speed Impact Test on the Fiber-Metal Composite Toughened with NBR Elastomer

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Abstract

In this experimental study, low velocity impact test with different energy levels was performed on a fiber-metal (FML) structure reinforced with NBR elastomer. The FML structure consisted of a 2024 layer of aluminium as the core, two layers of NBR elastomer on both sides of the aluminium and a composite layer after the NBR layers, which were made by hand layup method. The composite layers were made of bi-direction carbon fiber fabric as well as phenolic resin. Also, the knocker was made from very high hardness and hit the FML sample with various energy levels (50, 58 and 66 joules). Thus, in the present paper, the effect of different composite thicknesses on the front and back of the core against the three impact energies was studied. One of the notable innovations in this work is the use of NBR elastomer, which acts as a reinforcement in withstanding impact loads. Based on the obtained results, the maximum and minimum amount of contact force, absorbed energy, deformation and contact time was related to P \ldots 2.2 and P \ldots 1.1 samples. By comparing the P \ldots 2.1 and P \ldots 1.2 samples after the impact test, it was shown that P \ldots 2.1 samples has a softer behaviour.

Keywords: FML Hybrid Composite, Low velocity impact, Impact energy, NBR elastomer

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1. Introduction

Loss of weighting of structures by improving mechanical properties and other properties has the particular importance in the transportation industry such as the automotive, aerospace and shipbuilding industries [1-5]. Lightweight structures with more fleet carrying capacity have the higher speed capability and lower fuel consumption. For this reason, the growth in the use of sandwich materials structures as new materials have received remarkable attention in recent years. Increasing demand for lighter vehicles has led transportation industry to replace and build different structures than ever before. Meanwhile, the vacuum of familiarity with the mechanical behaviour and strength of some new advanced materials has become clear. The growth in the use of sandwich structures requires sufficient knowledge of all aspects of the difference between these structures and common materials. Consequently, in order to overcome this problem, further studies in the field of understanding the mechanical behaviour of sandwich structures are required. In addition, understanding the impact phenomena and dealing with vehicles in land, air and sea at low speeds is critical that in the meantime, it seems necessary to know the behaviour of sandwich structures due to their high energy absorption capacity [6-7]. Impact on the fuselage can include low-velocity shocks such as falling loads on the fuselage, collisions with cars and pebbles, and tools falling on the fuselage or bullets hitting the fuselage of warplanes. Any collision that has a speed of less than 10 meters per second falls into this category of collisions [8-11]. Ashna Ghasemi et al. [12] investigated the dynamic response of a high-strength composite metal sheet under impact with small and large objects. According to the obtained results, the use of thin aluminium sheet between composite layers can improve the impact strength of the sheet. Jaroslaw et al. [13] compared the multilayers behavior of metal-glass fiber-epoxy / aluminium and carbon fiber-epoxy / aluminium. They investigated the effect of fiber orientation as well as analysis of loading time of damage area and depth of destruction and their relationship with different energy levels. The obtained results make it possible to determine the specific points that may occur at certain stages of the degradation process of the multilayer structure. These modes of destruction include local microcracks and delamination which reduces the stiffness of the multilayer and causes more damage due to cracks in the layer. Also, they found that multilayers containing the carbon fiber were more prone to perforation than multilayers containing the glass fiber and delamination in composites and separation between metal and fiber plates to be the main mode of degradation in metal-fiber multilayers. Moreover, the authors reported that in floret multilayers, the energy absorption mainly is carried out through plastic deformation as well as through delamination and their dispersion. While in coral multi-layer (carbon-epoxy / aluminium fibers), the impact energy absorption occurs through penetration and perforation of the multilayer .Metal-fiber multilayers based on thermoplastic composites were investigated by Cantwell et al. [14]. They showed that these multilayers had better properties in terms of impact analysis and energy absorption and fracture toughness than thermoset matrix multilayers. Boroujerdi et al. conducted a experimental and analytical study of low velocity impact on metal-fiber multilayers. They found that as the initial impact velocity and the resulting impact energy increased, the number of separated layers, the separation area between the broken layers, increased. While the energy absorption process of the samples does not change with increasing impact speed [15]. Siddiqui and Dariushi investigated the effect of fiber angle on the absorption energy of low velocity metal-fiber multilayers. They used two sharp impact instruments with energies of 6 and 150 joules. They concluded that the composite layers with zero fiber angles greatly increase the impact resistance of the sample, composite layers with a fiber angle of 90 degrees make the sample more brittle, and composite layers with a fiber angle of 45 degrees increase the absorbed energy if placed on the back of the sample. In fact, the applied force causes the composite to break on the 45 degree line and parallel to the fibers, and this type of
failure causes the aluminium layer in front of it to be torn. In other words, the aluminium layer first undergoes a lot of plastic strain and then breaks, which causes a lot of energy to be absorbed by this layer [16]. Ramezani Parsa and Eslami experimentally investigated the effect of amplification of different pre-strains of nitinol memory alloy wires embedded in metal-fiber multilayers against low velocity impact. They used a falling impact instrument to perform their experiments. The studied multilayer material was aluminium-glass-epoxy in which 6 wires with pre-strains of 1, 2 and 3% were embedded. The obtained results showed that by increasing the pre-straining of the wires, the duration of impact of the impact with the part increases and the shock of the impact force of the impact and the amount of damage decreases [17]. In an experimental study, Torabizadeh analyzed the behavior of sandwich aluminium foam sheets in two types of interconnected procedures and separate procedures against low-speed impact load and their failure shape using computer cross-sectional images [18]. The results of this study indicate that the final destruction and complete failure of aluminium sandwich panels compared to polymer sandwich panels have a smaller range and healthier than samples after impact, so their mechanical properties and performance will be better after impact. In other studies, on foam core sandwich panels, Golestani Pour et al. [19, 20] investigated the amount of energy absorption in foam core sandwich panels. Avila et al. [21] investigated the behaviour of composite sheets by impact at low velocities. They investigated the effect of changing the volume percentage of nano clay on the amount of contact force at different levels of impact energy. They reported that the samples with 5% volume fraction of nano clay show the best performance compared to contact force damping. Ji-Fan et al. [22] investigated the low-velocity impact response in fiber-metal multilayer composites and simple composites. According to the obtained results, the fiber-metal multilayer composites have higher perforation resistance than simple composites. Goo et al. [23] numerically investigated fiber-metal, coral, and glare multilayer composites under low impact velocity. The simulation results for coral show larger critical loads and smaller displacements under the same impact energy. They also investigated the effect of different aluminium alloys on the impact resistance of coral and showed that by increasing the yield strength of aluminium alloy, the impact resistance properties are improved. Tsaris et al. [24] studied the impact resistance of fiber-metal multilayer composites under low velocity and then were able to provide an optimal design for the impact resistance of aerospace applications. They also showed that fiber-metal multilayer composites are able to absorb energy through plastic deformation and fracture between layer interfaces. In particular, delamination has occurred on the back of the aluminium alloy sheet and adjacent to the fiber-reinforced epoxy and between the layers. Ji Fan et al. [25] investigated hole failure in three different layering of fiber-metal multilayer composites under low velocity impact. As reported, with increasing the thickness via enhancing the number of layers, the impact resistance can increase. Increasing the size of the projectile and the size of the plate leads to an increase in the energy of the perforation and change the location of the projectile impact, has little effect on the impact response in this type of composites. Ning et al. [26] evaluated the improvement of mechanical properties of fiber-metal multilayer composites based on carbon and aluminium reinforced composites by various methods. The test results showed an improvement in mechanical properties through acid etching and addition of nano materials, which effectively improves the critical load and fracture toughness of the first mode. Zamani et al. [27] investigated the mechanical properties and high impact of polypropylene nanocomposites with multi-walled carbon nanotubes. In this study, the impact strength for the perforated nanocomposite sample is increased to prevent crack propagation. The Young's modulus and yield strength of polymer composites are increased by the addition of nano carbons. However, the forming ability of the composite has decreased with increasing percentage of multi-walled carbon nanotubes. Liang Zhang et al.[28] studied the influence of
viscoelastic parameters, and radius curvature on the free, and forced vibration characteristics of a model under low-velocity impact. Then, the influence of density of knocker, and weight fraction of the graphene nanoplatelets on the indentation, contact force, absorbed energy in panel, and indenter velocity investigated. The obtained results exhibited that the designer, as the weight fraction of the reinforcement increases, the maximum absorbed energy of the GPLRC (Graphene nanoplatelets reinforced composite) panel could happen in less time. Khademzadeh et al[31] studied the effect of nanosilica and compatibilizer on the morphology, mechanical properties, and linear rheology of the PLA/EVA blends. He found the simultaneous addition of nanoparticles and SEBS-g-MA led to synergistic toughening effects and the compatibilized blend containing nanosilica exhibited excellent impact toughness. According to previous studies, the use of NBR rubber and aluminum sheet as the core of fiber-metal composites and their behavior against low speed impact has not been investigated. To the best of our knowledge, this is the first report about evaluation of the effect of composite layer thickness, impact energy and the effect of thick and thin composite layers exposed to impact of knocker. It is necessary to mention that, the composite used in this research manufactured of carbon fiber fabrics and phenolic resin. Therefore, the aim of this study is to investigate the effect of 50, 55 and 66 joule impacts on a hybrid composite that in the core of it the 2024 aluminium sheet and NBR rubber have been used, and the back and top of the core, carbon fiber-resin composite in different thicknesses, has been used. Consequently, in the present study, the effect of the different thicknesses of the composite on the front and back of the core on the three impact energies has been investigated and attractive results has been reported.

2. Experimental
2.1. Materials
In this research, fiber-metal multilayer samples including two composite surfaces and the core consisting of aluminium sheet and NBR rubber, were formed. The aluminium used in the core was made of Al 2024-T3 with a thickness of 0.5 mm. Proper surface preparation of aluminium sheets was inevitable to ensure the adhesive strength of the composite layers to the metal.

<table>
<thead>
<tr>
<th>Tensile strength (MPa)</th>
<th>Yield strength (MPa)</th>
<th>Elongation at break(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>434-441</td>
<td>289</td>
<td>10-15</td>
</tr>
</tbody>
</table>

NBR rubber was glued to the top and bottom of the aluminium sheet. Table 2 presents the properties of the used NBR rubber, respectively.

<table>
<thead>
<tr>
<th>Tensile strength (MPa)</th>
<th>Yield strength (MPa)</th>
<th>Hardening temperature</th>
<th>Elongation at break(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>67.8</td>
<td>10.5</td>
<td>-200c</td>
<td>150-400</td>
</tr>
</tbody>
</table>

In order to make the composite layers that are placed on both sides of the hybrid composite material, a woven carbon fabric (Torayca T300 carbon fiber) weighing 200 grams per unit area was used. Also, the phenolic resin under the brand name IL800 (Resol type IL800 with red color and manufactured by Rositan Company) was used.

2.2. Drop weight Impact Test
In order to determine the fracture energy of metals and composite materials, gravity or drop weight testing device has been used. The ASTM D2444 standard was applied for this type of test. This device detects the impact phenomenon not through pre- and post-impact energy, but by giving information during the impact time. In this device, the impact load is applied by dropping a weight whose weight can be changed. The device has barriers that allow the user to adjust the height of the fall, so it is easy to determine the initial energy of the fall and applying it to the sample. In order to perform this test, a low speed impact device was used which was in accordance with the impact test standard. Also, transferred the data that were recorded by the dynamometer sensor installed on the impact (including a 2.7 kg head made of hardened steel) to the computer, a data collection device was used to deliver the force-time curve to the user on time. To test, the samples were placed between two plates, then, by closing the four clamps that connected to the device body, the samples were fixed between the two mentioned plates and were prepared for the test and were hit. The knocker was connected to a plate by two locks, which opened the locks to test and the knocker is released. Fig 1 shows the gravity impact device.

![Gravity Impact Device](image1.png)

Fig 1. Setup of Impact test

### 2.3. Manufacturing of fiber-metal multilayers

Hand layup method was used to make of fiber-metal multi-layer. Various methods have been proposed to prepare the aluminum surface for adhesive bonding. In this study, in order to prepare the surfaces of the plates, the sandblasting method was used to prepare and degrease the plates. Fig 3 shows the prepared aluminum plate.

![Prepared Aluminum Plate](image2.png)
In this research, due to the use of NBR and the necessary requirements, the hand layup method has been used. In addition, in order to reinforcing effect between metal and composite and also the high adhesion of the NBR to composite surface, the NBR elastomer was used. First, carbon fiber fabrics were cut in 15 x 15 cm dimensions. Then the aluminum plates prepared from the previous stage, which have dimensions of 15 * 15cm, were sanded and prepared. And after ensuring that there was no oxidation on the aluminum primer and chemosile adhesive with codes 211 and 222, it was applied on the aluminum surface with a brush. After one hour of drying and ensuring the adhesion condition, the NBR was glued to the aluminum sheet. After the NBR was bonded, the air trapped between the metal and rubber layers was evacuated with a roller. This bonding was done in such a way that the ratio of 65% of fabric and 35% of resin was observed in the layers.

Fig 3. Phenolic resin and woven carbon fiber

Then the prepared sample placed in a hot press with a pressure of 5 tons and the defined curing cycle for the above-mentioned resin was carried out along with the application of pressure. It should be noted that by placing the element with central heating capability and raising the temperature to 135 °C, the stress in layers increases which leads to increasing of stiffness factor and impact resistance. Fig 4 shows some of the made samples.

Fig 4. Prepared samples for impact test

2.4. Samples and test conditions
In this study, 4 samples of hybrid composites with different thicknesses were made according to Fig 5 and were subjected to impact tests with energies of 50, 58 and 66 joules. It should be
noted that in this study, three levels of energy were obtained from fixed mass that were released from different heights.

Table 3  Sequence and thickness of each layer

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Thickness of Top composite layer(mm)</th>
<th>Thickness of bottom composite layer(mm)</th>
<th>Thickness of Top NBR layer(mm)</th>
<th>Thickness of bottom NBR layer(mm)</th>
<th>Thickness of Al layer(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P..1/1</td>
<td>1</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>P..1/2</td>
<td>1</td>
<td>2</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>P..2/1</td>
<td>2</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>P..2/2</td>
<td>2</td>
<td>2</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Fig 5. Schematic of the prepared samples.

Another factor that has been studied in this project was impact energy. In this research, all four types of samples that were shown in Fig 5 were tested under three impact energies. Therefore, according to the explanations provided in Table 3, the test samples have been coded.
According to Table 3, the meaning of the back layer was the side of the hybrid composite that does not strike with the knocker. The top layer also referred to the part of the specimen that the knocker strikes during the test. It is noteworthy that the samples of low speed impact test were prepared according to the standard in the dimensions of 20 * 20cm. All tests (Table 3) were performed by a hemispherical knocker and its accessories (accelerometer sensor, bearing, etc.) with a mass of 2.7 kg, which strikes the samples from three different heights. Impact velocity and height were obtained using Eqs (1,2) in order to achieve three energy levels of 50, 58 and 66 joules [29].

\[
E = mgh \\
V = \sqrt{2gh}
\]

In Eqs (1,2), E is the impact energy, m, the impact mass, g is the gravitational acceleration, \( h \) is the fall height, and V is the impact velocity. When the knocker strikes the specimens, the acceleration data over time is recorded by a sensor mounted on the knocker and transmitted to the computer via a controller. According to the test results, disturbing signals were observed at the output. By using the averaging method, a curve was passed through the response outputs.

<table>
<thead>
<tr>
<th>codes</th>
<th>Energy(J)</th>
<th>Composite thickness(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P501/1</td>
<td>50</td>
<td>1 mm top layer and 1 mm bottom layer</td>
</tr>
<tr>
<td>P502/2</td>
<td>50</td>
<td>2 mm top layer and 2 mm bottom layer</td>
</tr>
<tr>
<td>P502/1</td>
<td>50</td>
<td>2 mm top layer and 1 mm bottom layer</td>
</tr>
<tr>
<td>P501/2</td>
<td>50</td>
<td>1 mm top layer and 2 mm bottom layer</td>
</tr>
<tr>
<td>P581/1</td>
<td>58</td>
<td>1 mm top layer and 1 mm bottom layer</td>
</tr>
<tr>
<td>P582/2</td>
<td>58</td>
<td>2 mm top layer and 2 mm bottom layer</td>
</tr>
<tr>
<td>P582/1</td>
<td>58</td>
<td>2 mm top layer and 1 mm bottom layer</td>
</tr>
<tr>
<td>P581/2</td>
<td>58</td>
<td>1 mm top layer and 2 mm bottom layer</td>
</tr>
<tr>
<td>P661/1</td>
<td>66</td>
<td>1 mm top layer and 1 mm bottom layer</td>
</tr>
<tr>
<td>P662/2</td>
<td>66</td>
<td>2 mm top layer and 1 mm bottom layer</td>
</tr>
<tr>
<td>P662/1</td>
<td>66</td>
<td>2 mm top layer and 1 mm bottom layer</td>
</tr>
<tr>
<td>P661/2</td>
<td>66</td>
<td>1 mm top layer and 2 mm bottom layer</td>
</tr>
</tbody>
</table>
to reduce the disturbing signals. In addition, suitable low-pass filters were used to eliminate the high frequency signal. After this, Using Eq (3), the acceleration-time data were converted to force-time data. [29]

\[ F(t) = ma(t) \]  \hspace{1cm} (3)

In Eq (3), \( F(t) \) is the contact force at each moment of the test, \( m \) is the impact mass, and \( a(t) \) is the striking acceleration at each moment of the test. After recording the contact force data in terms of time, Using Eq (4), the velocity data in terms of time were obtained [29]

\[ V(t) = V_0 - \int a(t) \, dt \]  \hspace{1cm} (4)

In Eq (4), \( V(t) \), the strike velocity, \( V_0 \), the strike velocity before the strike, and \( a(t) \), is the momentary acceleration. After recording the velocity /time data, if the knocker penetration into the fiber-metal multilayer is neglected, knocker displacement can be equated to the fiber-metal multilayer displacement, which is calculated from Eq (5) [29]

\[ \delta(t) = \int V(t) \, dt \]  \hspace{1cm} (5)

In Eq (5), \( V(t) \) is the strike velocity and \( \delta(t) \) is the knocker displacement. By recording velocity data in terms of displacement, the absorbed energy is calculated using Eq (6) [30]

\[ E = \int F \delta(t) \, dt \]  \hspace{1cm} (6)

In Eq (6), \( E \) is the absorbed energy, \( F \) is the contact force, and \( \delta(t) \) is the knocker displacement. In order to extract the above data, coding in MATLAB software has been used. Also, after extracting the above data, the damage of the samples has been investigated experimentally.

3. Results and discussion

As stated in the previous sections, the number of samples examined in this study is 12 samples and 3 replications have been done for each sample.

In this section, force-time, force-displacement, energy-force and maximum force diagrams are presented for the following three modes:

- Four samples of impact hybrid composites with energy of 50 joule
- Four samples of impact hybrid composites with energy of 58 joule
- Four samples of impact hybrid composites with energy of 66 joule

In the results section, in order to investigate the failure mechanism in these samples, fracture mapping of the optimum samples was drawn.

3.1. Effect of 50–joule impact on the studied composite

After performing P501 / 1, P502 / 2, P501 / 2, P502 / 1 samples, the curves of force-time, force-energy and displacement force diagrams for 50 joules were presented. Fig 6 shows the time force diagram for the above four tests.

\[ F(t) = ma(t) \]
\[ V(t) = V_0 - \int a(t) \, dt \]
\[ \delta(t) = \int V(t) \, dt \]
\[ E = \int F \delta(t) \, dt \]
Examining the force-time diagram for the 50 joule test, it can be concluded that the maximum contact time belongs to the P502 / 2 sample, which means that the P502 / 2 sample has a softer behavior than the other three samples. Also, according to Fig 6, P502 / 1 and P501 / 2 samples have less contact time than P502 / 2 and P501 / 1, which indicates the relative brittleness of these samples. The reason for this can be attributed to the asymmetric thickness of the composite in samples P502 / 1 and P501 / 2. According to this Fig6, the maximum contact force of the sample is P502 / 2, which is due to its greater thickness. By comparing the maximum force in P502 / 1 and P501 / 2 samples, a slight difference is observed, so the displacement of thick and thin composite layers at 50 joules impact has a greater effect on the contact time.

Fig 7 shows the four examples of force-displacement diagram for the 50- joule impact.

With examining Fig 7, it is clear that the maximum force and minimum displacement at the moment of maximum load has been borne by the P502 / 2 samples. From this perspective, the best behaviour under 50 joules impact was shown by P502 / 2 sample. According to Fig 7, the maximum displacement for the P501 sample was about 25 mm. Therefore, this sample is more tolerant of deformation.
In the following, power-energy diagrams and maximum absorbed energy were studied. Fig 8 shows the energy-force diagram for the above four samples.

![Power-energy diagram for the 50-joule impact](image)

According to Fig 8, the area under the diagrams for sample P502/2 is larger than the rest of the samples. As known, strain and energy and force have direct relationship with stress. Just as the area below the strain-stress diagram represented toughness, so the area below the energy-force diagram also represents stiffness. According to the explanation, it can be said that the toughness of P502/2 sample has the highest and the P501/1 sample has the lowest toughness. It should be noted that the toughness of P501/2 is higher than P502 and both of these samples are less than P502/2.

Fig 9 shows the maximum energy absorbed in all four samples P501/1, P502/2, P501/2, P502/1.

![The Maximum of absorbed energy in P501/1, P502/2, P501/2, P502/1](image)

According to Fig 9, the maximum energy for the sample is 2.502 and the minimum for P501 is 1.1. Therefore, increasing the thickness of the composite increases the amount of energy absorption.
3.2. Effect of 58-joule impact on the studied composite

The force-time, force-energy and force-displacement diagrams obtained from the impact device were studied. First, samples P581 / 1.5, P581 / 2.5, P582 / 1.5 and P582/2 were tested with an energy level of 58 joules. Because acceleration was recorded over a long period of time, as well as the effect of vibration, the parts that are not part of the impact process must be refined from the impact curve. The results showed the obtained acceleration-time diagram has the lots of dispersion. To extract force-time diagrams, it was necessary that the acceleration-time diagram needs to be continuous. For this purpose, the MATLAB software and the Violet command curve were refined and continuous.

As can be seen, P582 / 2 and P581 / 1 have higher contact times (between the sample and the colliding body). It is also noticeable that in P582 / 1 the contact time is much lower than other samples. It should be noted that due to asymmetric geometry, P581 / 2.5 and P582/1 have much shorter contact times than P581/1. Also, due to the lower thickness of P581 / 1, this sample has a much lower maximum force than other samples.

A comparison of the force-displacement diagram for the four samples at 58 joules was given in Fig 11. As can be seen, the sample P582 / 2 has a higher maximum force than others (between the specimen and the colliding body). As can be seen, the P581 / 1 has a much lower maximum force than other specimens.
As shown in Fig 11, the highest displacement is related to P581/1 and the lowest displacement is related to P582/2 and P582/1. Therefore, although P582/2 and P582/1 samples withstood more force, but less displacement occurred in them. And this indicated that in these two samples the deformation speed was high. Fig 12 shows the force-energy diagram for four samples under the 58 joule impact.

![Force-energy diagram for 58- joule impact](image)

According to Fig 12, the area under the curve for sample P502/2 was larger than the rest of the samples.

### 3.3. Effect of 66- joules impact on the studied composites

Fig 13 shows the effect of a 66 joule impact on the force-time diagram of four samples, P661/1, P661/2, P662/1 and P662/2.

![Force-time diagram for 66- joule impact](image)

According to Fig 13, by comparing the force-time diagrams, it can be easily seen that the P662/2 sample with a 2 mm composite layer on both sides, has the maximum contact force and the maximum contact time. This means that in the 66 joule impact test, the P662/2 has the higher impact resistance. Another noteworthy point in Fig 13 is that the maximum contact force for the P661/2 and P662/1 samples, differs from each other. However, the maximum contact time in P661/2 sample was about 20% longer than P662/1 sample which was showed a significant difference and this indicated the softer behavior of sample P661/2 than sample P662/2.

Also, as shown in Fig 13, the maximum contact time for P661/2 and P662/1 samples is shorter than for P661/1 sample.
And the reason for this attractive result was the non-uniform thickness of the composite in the top and outer layer. In other words, the non-uniform thickness of the composite in the surface and outer layer was a kind of defect.

In the following of this section, force-displacement diagrams for four samples under the impact of 66 joules were examined. Fig 14 shows the energy-force diagram at 66 joules for the four samples P661 / 1, P661 / 2, P662 / 1 and P662 / 2.

![Force-displacement diagram for 66-joule impact](image)

According to Fig 14, the maximum force and the minimum displacement at the moment of maximum force are in the P662/2 sample. Carefully in this Fig, due to this fact that the above three samples were more resistant than the P661/1 sample, it was clear that the slope of the force increasing in the samples P661 / 2, P662 / 1 and P662 / 2 compared to the sample P661 / 1 was very steep. Although the P661 / 1 model had less resistance and less force tolerance, but had more displacement at the moment of maximum load, which indicated the soft behavior of this sample.

Fig 15 shows the force-energy diagram for four samples under the 66 joule impact.

![Energy-displacement diagram for 66-joule impact](image)

According to Fig 15, the area under the diagrams for sample P662 / 2 is larger than other samples. As known, strain and energy have a direct relationship and force has such relationship with stress. Just as the area below the strain stress diagram represented toughness, so the area below the energy-force diagram also represents stiffness. According to the presented
explanation, it can be said that the toughness of P662 / 2 has the highest and the P661 / 1 has the lowest. It should be noted that the toughness of P662/1 is less than P661/1 and both of these samples are less than P662/2. According to Fig 15, the area below the force-energy diagram in the P662 / 1 and P661 / 2 samples is slightly different, which is an attractive result in terms of 66 joules for this hybrid composite. According to Fig 15, at the moment when the contact force was zero, the P662 / 2 sample had the lowest energy and the highest energy in these conditions was belong to the P661 / 1 sample. This indicated that the P662 / 2 sample absorbed more energy than the impact test knocker. In other words, the P662 / 2 had the ability to absorb more energy.

3.4. Investigation of samples after the tests

In order to investigate the damage and degradation in hybrid composite samples that have been subjected to impact test, the samples were examined in term of appearance. The samples of the tests were divided into four groups of three and were visually examined. Also, by comparing the samples after the test, can be realized the accuracy of the results.

Therefore, in Fig 16, samples of P502 / 2, P582 / 2 and P662 / 2 after the impact test are presented.

![Fig 16. P502 / 2, P582 / 2 and P662 / 2 samples after impact test](image)

According to Fig 16, failure did not occur in samples with a composite thickness of 2 mm on both sides. This indicates sufficient resistance of these samples to all three impact energies. According to Fig 16, it can be seen that the damage caused to the corrosive impact surface in the samples was a type of depression that its amount in P502 / 2 sample was less than other samples.

![Fig 17 shows P501 / 1, P581 / 1 and P661 / 1 samples after impact test](image)
According to Fig 17, in specimens with a composite thickness of 1 mm on both sides, failure occurred in specimens subjected to 66 joule impact but the samples that were hit at 50 and 58 Joules did not fail. Therefore, for specimens with a composite thickness of 1 mm on both sides, the maximum impact energy was 58 joules. In other words, the resistance limit of these sheets has been up to 58 joules of impact energy.

Fig 18 shows P502 / 1, P582 / 1 and P662 / 1 samples after impact test.

According to Fig 18, in specimens with a composite thickness of 2 mm on the top and 1 mm on the bottom, failure occurred in specimens subjected to 58 and 66 joules, but in specimens subjected to 50 joules, the fracture not occurred. Therefore, for samples with a composite thickness of 2 mm on the top and 1 mm on the bottom, the maximum impact energy was 50 joules. In other words, the resistance limit of these sheets is up to 50 joules of impact energy.

By observing the image on the right in Fig 18 with a little more precision and more sensitivity, it can be said that under all three impacts of 50, 58 and 66 joules, the samples have been damaged. And in the 58 and 66 impacts, the test bullet tore the sample, but in the 50 impact, only one side of the sample has been torn.

Fig 19 shows P501 / 2, P581 / 2 and P661 / 2 samples after the impact test.
According to Fig 19, the failure was occurred in samples subjected to 58 and 66 joules, but failure not occurred in samples subjected to 50 joules. Therefore, for samples with a composite thickness of 1 mm on the top and 2 mm on the bottom, the maximum impact energy was 50 joules. In other words, the resistance limit of these sheets has been up to 50 joules of impact energy.

By comparing Figs 18 and 19 that presented in Fig 20, an attractive result was obtained.

According to Fig 20, specimens with a top layer of 1 mm (type A specimens) had undergone more deformation. In other words, type A samples showed the softer behavior. The fact that Type A specimens behaved softer means that they have had a longer contact time than Type B specimens. According to the force-time diagrams that were presented in detail in the previous sections, it was observed that the maximum contact time in type B samples was longer than type A samples, which confirmed the soft behaviour in type B samples. By observing the Fig 20 with a little more precision and sensitivity, it can be said that Type A specimens have been damaged under all three impact of 50, 58 and 66 joules. However, in type B specimens, the failure occurred in 58 and 66 impacts, in other words, Type B specimens has behaved better against impact load.

4. Conclusion
Initially, in this research, four types of five-layer hybrid composites were made. Type 1: The middle layer of aluminum and NBR on both sides was placed and then the carbon-resin fiber composite with a thickness of 2 mm was placed on both sides of the aluminum-NBR structure. Type 2: The middle layer of aluminum and NBR was placed on both sides and then the carbon-resin fiber composite with a thickness of 1 mm was placed on both sides of the aluminum-NBR structure. Type 3: The middle layer of aluminum and NBR were placed on both sides, and then the carbon-resin fiber composite layers with a thickness of 2 and 1 mm were placed on the top and bottom of the aluminum-NBR structure, respectively. Type 4: The middle layer of aluminum and NBR were placed on both sides, and then the carbon-resin fiber composite with a thickness of 1 and 2 mm was placed on the top and bottom of the aluminum-NBR structure, respectively. Therefore, fabricated four types of layered composites in this study and were tested with three impact energies of 50, 58 and 66 joules with low speed. In this study, three impact variables of 50, 58 and 66 joules were examined on four types of samples. Thus, 12 different modes were obtained to examine the time-force, displacement-force and force-energy diagrams in this research. The most important results after analysis have been presented below:

- In all three impact energies of 50, 58 and 66 joules, the P… 2.2 samples had maximum contact force, maximum contact time and energy.
- In all three impact energies of 50, 58 and 66 joules, the maximum contact time was in the P… 1.1 samples that it was more than P… 2.1 and P… 1.2 samples.
- In all three impact energies of 50, 58 and 66 joules, the maximum contact force in the P… 1.1 samples was less than P… 2.1 and P… 1.2 samples.
- The appearance checking of the samples showed that the P… 1.1 samples had a softer behavior than P / 2.1 and P… 1.2 samples.
- In all three impact energies of 50, 58 and 66 joules, the maximum contact force in the P… 1.2 samples was higher than the P / 2.1 samples. But in the case of maximum contact time, the situation was the opposite. Also, after impact test, the appearance checking of P … 2.1 and P… 1.2 samples showed that the P… 2.1 samples have a softer behaviour than others.
- In samples where the thickness of the composite was different on both sides, the damage was more than other samples.
- In samples where the thickness of the composite was considered different on both sides, it was better to have a thin layer of the sample to be in contact with the bullet.

Considering the shape of force-time curves and reviewing the documents, it can be said that in the samples under the applied forces, the failure does not occur in the samples or the shear failure mode has been prevailed. Finally, the results showed that in the P…2.2 samples, the amount of energy absorption increased about 40%.

5. References


31- Moradi S, KhademzadehYeganeh J. Highly toughened poly(lactic acid) (PLA) prepared through melt blending with ethylene-co-vinyl acetate (EVA) copolymer and simultaneous addition of hydrophilic silica nanoparticles and block copolymer compatibilizer. Polymer Testing, 2020; 91: 106735.