Experimental investigation on the effect of stacking sequence on mechanical properties of the hybrid composites designed for light impact loads.

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Abstract: *Many materials are being developed today to withstand light impact loads for a variety of applications, including the manufacturing of vehicle rider helmets. The materials used for these applications should be lightweight and able to sustain the impact loads without suffering any serious damage. To this day, numerous researchers have generated a variety of composite materials with favorable strength to weight ratios. In the current research, an effort was made to create a composite material of this type that is both affordable and capable of withstanding light impact force. For the current experiment, three full composites made of carbon, aramid, and glass fibres as well as three hybrid composites made from the combination of the above-mentioned fibres are created by stacking the two layers of each fibre in various combinations and by following various stacking sequences. The general-purpose polymer is the matrix material used for all six test specimens. The ASTM standards were followed for conducting mechanical testing such as the Tensile test, Short beam bending/interlaminar shear stress test, Flexural/Three point bending test, Izod test, and Hardness test. The findings show that full carbon composite specimens outperform the other evaluated specimens in the majority of the tests. In the majority of the tests, the full glass fibre composites exhibit normal performance. However, compared to other studied combinations, its mechanical properties are improved when coupled with carbon fibres. As a result, carbon and glass hybrid composites perform well and are more cost-effective than full carbon composites for light impact loads.*

Keywords: *Hybrid composites, light impact load, mechanical properties.*

1. Introduction:

Composite materials commonly used for light impact applications such as helmets includes Carbon fiber composites, Glass fiber composites, Aramid or Kevlar fiber composites etc. The listed materials are selected for their high strength-to-weight ratio, better impact resistance and ability to absorb and distribute the impact force. The specific composite materials and their arrangement are varying depending on the purpose to use and protection level required for the helmets. Fiber glass composites are made by reinforcing the resin with glass fibers. These are strong, lightweight and economical. Carbon fiber composites possesses high-strength and these are produced reinforcing the resin with strong carbon fibers. These composites exhibits excellent impact resistance and durability. These composites are very expensive. Even though Aramid fibers such as Kevlar are having good strength, they generally combine with other materials and bit costlier in comparison with glass fibers. In addition to above listed composites High Density Polyethylene (HDPE) is also used to produce the helmets to use in construction field. In order to enhance the mechanical properties of the composites to withstand the maximum impact load, hybrid composites are produced by combining two or more fibers together.

Huge amount of research work has been done in order to find a material which should have impact sustaining capacity, which can produce with ease and which can be reasonable in cost. Some researchers are attempted to design and analyze the hybrid composite materials for the sports applications [1]. Some of the researchers are tried to optimize the composite proportions by varying the volume of reinforcement of various materials [2]. Development of hybrid composites were done to obtain the maximum protection for the head by combining Carbon, Kevlar and HDPE [3]. Different types of pure fiber and hybrid composites are tested to estimate the damage caused by the low energy impact force and medium energy force [4-7]. In addition to the riding helmets and workers helmets low energy impact materials are tested for other applications such as car bumpers [8]. Different methods such as changing in volume fraction of the fiber reinforcement, changing the orientation of the fiber and combining of different fibers are tried to enhance the impact sustainability of the material [9-12]. Like this way in this work an attempt has been made to estimate the effect of stacking sequence of various material on the impact energy bearing capacity of the composite material. Test composites are prepared by following the different way of stacking sequence and mechanical properties of each composite are tested according to ASTM standards and comparison of the results have been made to identify the better composite material for low impact energy applications with possible low cost.

2. Methodology:

Preparation of test specimens: Test specimens are prepared with hand layup method. The matrix material used is the general-purpose resin and hardener used is MEKP. In total six varieties of specimens are prepared with by following the different stacking sequence as given in Table 1.

Table 1: Types of specimens prepared

Sl No.	Laminate composition
1	6 layers of Carbon fibers
2	6 layers of Glass fibers
3	6 layers of Kevlar fibers
4	2 layers of glass fibers+2 layers of carbon fibers+2 layers of glass fibers
5	2 layers of carbon fibers+2 layers of glass fibers+2 layers of carbon fibers
6	2 layers of Kevlar fibers+2 layers of carbon fibers+2 layers of Kevlar fibers

Mechanical testing: Following mechanical tests were done in order to know the mechanical characteristics of the various types of specimens prepared.

- Tensile test as per ASTM-D638-04 standards.
- Short beam bending test as per ASTM D2344 standards.
- Flexural / Three-point bending test as per ASTM D 790 – 10 standards.
- Izod impact test as per ASTM 256 – 10 standards.
- Hardness test.

2.1 Tensile test:

The tensile test was carried on universal testing machine. The experimentation was carried out in accordance with ASTM D-638-04 standards. The test specimen prepared according to the dimensions of ASTM D-638-04 is presented in Figure 1.

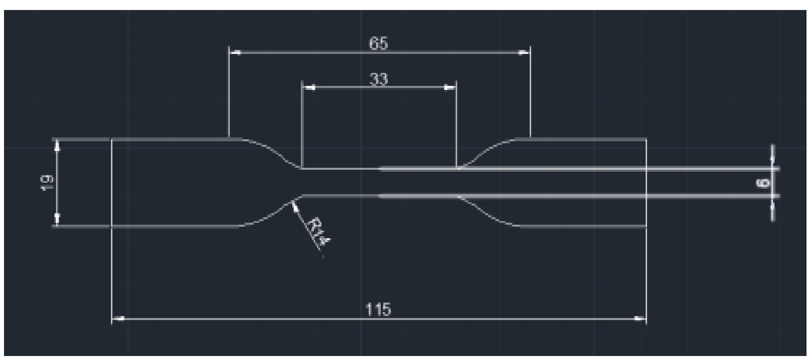

Figure 1: Tensile test specimen

All specimens are standardized, Zwick /Roell Z020 UTM was used for the test with a load cell of 20KN. A span-depth ratio of 16 was selected. Specimen was loaded uni-axially at a speed of 5mm/min and preload condition of 0.1MPa. The arrangement over the machine for the test is illustrated in Figure 2.

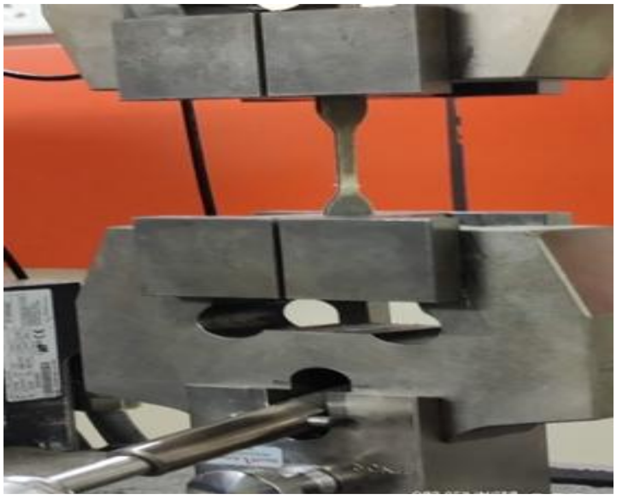

Figure 2: Full carbon composite laminate under tensile loading prior to failure

2.2 Short beam bending / Interlaminar shear stress (ILSS)

All specimens as per ASTM standards were chosen, Zwick/Roell UTM was used in the test having a load cell of 20Kn. Test speed was 1mm/min with a preload condition of 0.1 MPa. The span to depth ratio of 10mm was chosen. The dimensions of the specimen is illustrated in Figure 3.

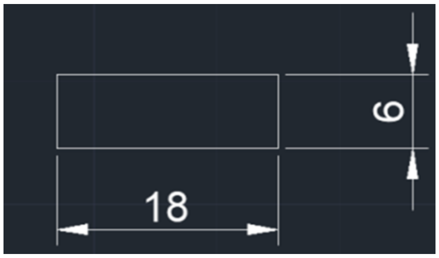

Figure 3: Short beam bending test specifications

2.3 Flexural testing/Three point bending test

Zwick /Roell Z020 UTM used for the test with a load cell of 20KN. Flexural support with adjustable span is used. Loading speed is 2mm/min and pre load condition is 0.1MPa. The dimensions of the ASTM standard specimen is given in Figure 4 and the testing setup is presented in Figure 5.

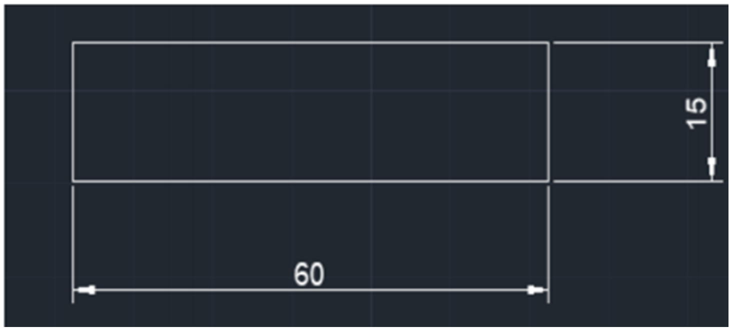

Figure 4: Flexural/Three point bending

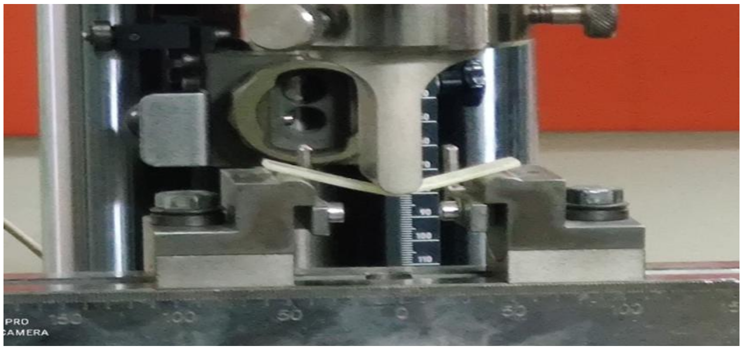
Figure 5: Failure of full Kevlar laminate under flexural loading.

2.4 Izod test

Test was carried out according to ASTM 256 – 10 standards using izod testing machine. The dimensions presented in Figure 6. Specimens are standardized with impact notch. Zwick /Roell HIT 50P was employed with a theoretical impact velocity of 3.456 ms-1. The test set up is presented in Figure 7.

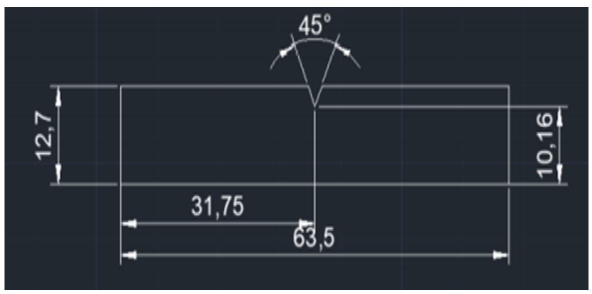

Figure 6: Izod test specifications

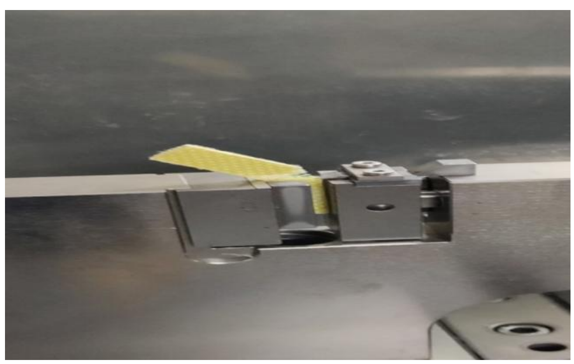
Figure 7: Izod test setting

2.5 Hardness tests.

Shore hardness tests were carried out on all specimens. Shore D hardness scale was used here owing to the hardness of the materials. Equipment used for the test was Zwick Durometer Hardness Tester.

3. Results and discussion:

3.1 Tensile test:

Table 2 displays the tensile test outcomes obtained from UTM for each of the six test specimens. The table shows that the complete carbon laminate had the highest tensile modulus & strength and was able to withstand the maximum force before failing. The laminate made entirely of Kevlar has the lowest young's modulus value. Full glass laminate failed with the least amount of stress.

Table 2: Tensile test results obtained from UTM

Legends	Specimen	Fmax N	Tensile Modulus MPa	Tensile Strength MPa	Strain@Break %	WIDTH mm	THICKNESS mm
(red)	Full Carbon	5320	2600	469	5.4	6	1.89
(green)	Full Glass	892	1520	78.7	2.6	6	1.89
(blue)	Full Kelvar	3500	826	184	5.9	6	3.17
(orange)	C+G+C	3293	974	253	5.1	6	2.17
(magenta)	G+C+G	1757	1450	145	4.5	6	2.02
(cyan)	K+C+K	3099	1520	191	5.1	6	2.71

Figure 8 displays the relationship between tensile strength and strain at break. Because of the fiber's characteristics, the full Kevlar fibre composite exhibits the highest elongation, as seen in the figure. Full carbon composite is the next one because it has superior ductile properties than glass. Full glass fiber composite exhibits the least elongation. This is because of the brittle nature of the glass. It is also clear that the elongation is lower in the hybrid composite when glass fibres are used as reinforcement.

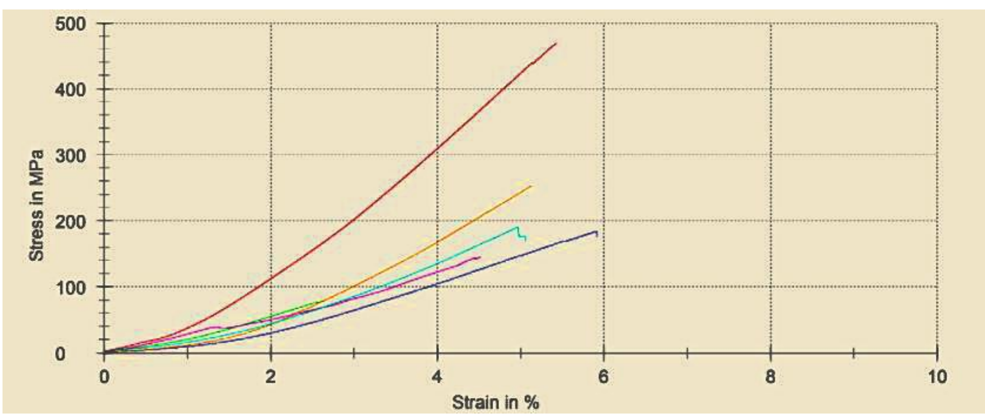

Figure 8: Stress versus strain plots

3.2 Flexural/Three-point bending test

For all six specimens the flexural results gathered from the UTM is presented in Table 3. The table depicts that, the laminated composite of full Kevlar withstood the maximum force before failure proves to have maximum resistance to bending. The full glass laminate has the least strength in bending. The carbon-glass-carbon laminate is shown to have the highest value of flexural modulus.

Table 3 displays the flexural data obtained from the UTM for each of the six examples. The table shows that the laminated composite made entirely of Kevlar resisted the most force before failing, demonstrating that it had the greatest bending resistance. The laminate made entirely of glass is the weakest when bent. The laminate made of carbon-glass-carbon is demonstrated to have the highest flexural modulus value.

Table 3: Three-point bending test results

Legends	SPECIMEN	FMax N	FLEX MODULUS MPa	FLEX STRENGTH MPa	THICKNESS mm	WIDTH mm	L mm
(red)	Full Glass	106.84	7860	144	1.89	15	48
(green)	Full Carbon	409.57	24300	528	1.93	15	48
(blue)	Full Kelvar	481.69	10400	259	2.99	15	48
(orange)	K+C+K	472.03	11600	309	2.71	15	48
(magenta)	G+C+G	121.98	6230	143	2.02	15	48
(cyan)	C+G+C	465.72	28500	466	2.19	15	48

Figure 9 depicts the deformation in response to the stress. The Kevlar-Carbon-Kevlar hybrid composite exhibits the most deformation before breaking, as seen in the image. This is as a result of Kevlar and Carbon fiber's superior ductile properties. The next is a full Kevlar composite. Due to the fragile nature of glass, full glass and glass fibre reinforced hybrid composites show the least amount of deformation.

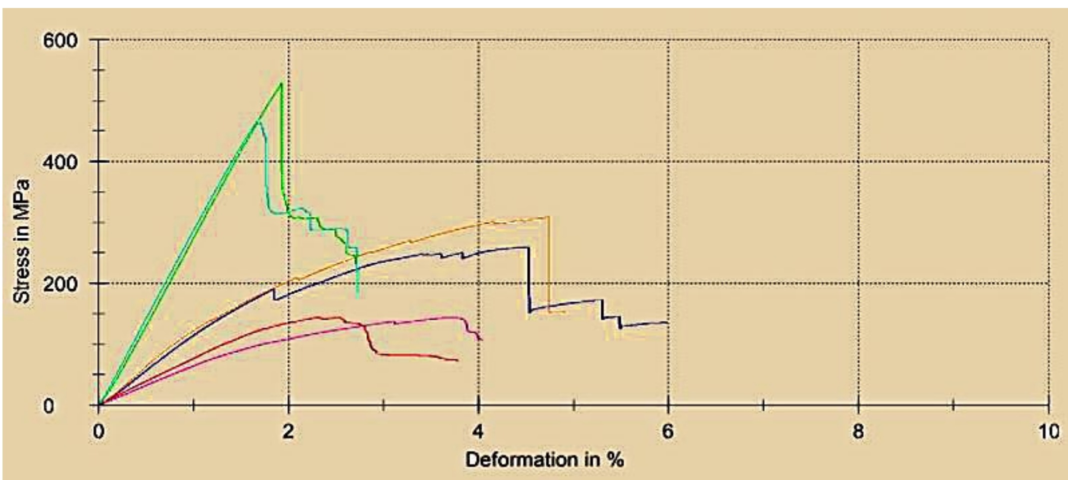

Figure 9: Stress v/s strain plots for flexural test.

3.3 Izod Impact test

The Izod impact test results are presented in Table 4. From the results it can be concluded that due to the properties like high strength, high modulus and toughness, the full Kevlar composite absorbed the maximum energy. Due to the high tensile strength of the carbon and glass fibers, the glass-carbon-glass hybrid laminate shows superior maximum amount of energy lost per unit thickness at the notch. The same data is presented in the graphical way in figure 10.

Table 4: Izod impact test results

Specimen Identifier	Width mm	Depth mm	Depth below the notch mm	Absorbed Energy J	Impact Strength J/m	Type of failure
K+C+K	2.8	12.78	11.120	1.941	630.27	P
Full glass	2.31	12.6	10.940	1.052	420.69	H
Full Kevlar	3.66	12.84	11.220	2.052	555.60	P
G+C+G	1.92	12.56	11.190	1.346	685.42	P
Full Carbon	2	12.64	11.450	1.117	547.51	C
C+G+C	2.34	12.61	10.790	1.167	517.41	H

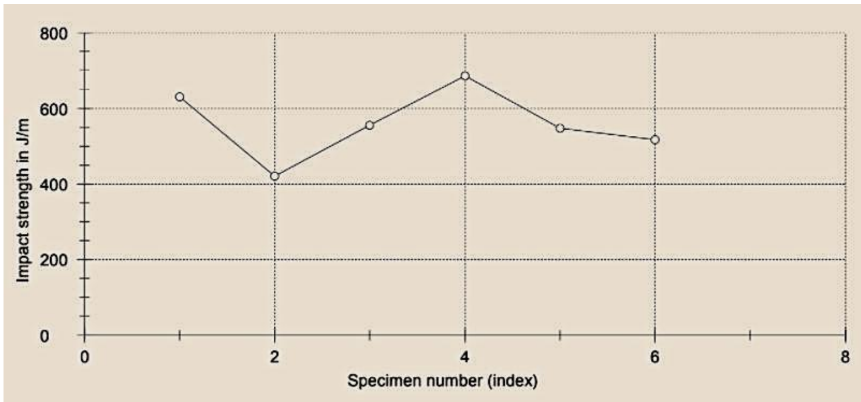

Figure 10: Impact strength based on indexing.

3.4 Short beam bending/Interlaminar shear stress (ILSS)

Table 5 presents the results of the short beam bending. The table shows that the whole carbon composite sustained the greatest amount of force, followed by the full Kevlar, which has superior bending capabilities due to its high modulus and toughness. The G-C-G composite with its poor bending capabilities on both sides and early failure absorbed the least force.

Table 5: Short beam bending/Interlaminar shear stress (ILSS) test results

Legends	SPECIMEN	FMax N	FLEX MODULUS MPa	FLEX STRENGTH MPa	THICKNESS mm	WIDTH mm	L mm
(red)	FULL CARBON	445.00	13300	517	1.88	5.84	16
(green)	FULL GLASS	160.68	4150	146	2.1	5.98	16
(blue)	FULL KEVLAR	428.09	455	116	3.68	6.52	16
(orange)	CARBON+GLASS+CARBON	352.78	5110	218	2.57	5.88	16
(purple)	GLASS+CARBON+GLASS	155.85	254	128	2.23	5.86	16
(cyan)	KEVLAR+CARBON+KEVLAR	323.20	728	166	2.75	6.17	16

Figure 11 displays the stress versus percentage of deformation plot. The picture makes it evident that the entire carbon composite material was able to withstand the highest stress, which, as we all know, was made possible by the stronger carbon fibres. C-G-C composite is placed next to complete carbon. In this instance, strength is decreased as a result of the decline in carbon fibre content. Because the glass fibres are fragile and have low bending qualities, C-G-C composite has the least flexural property.

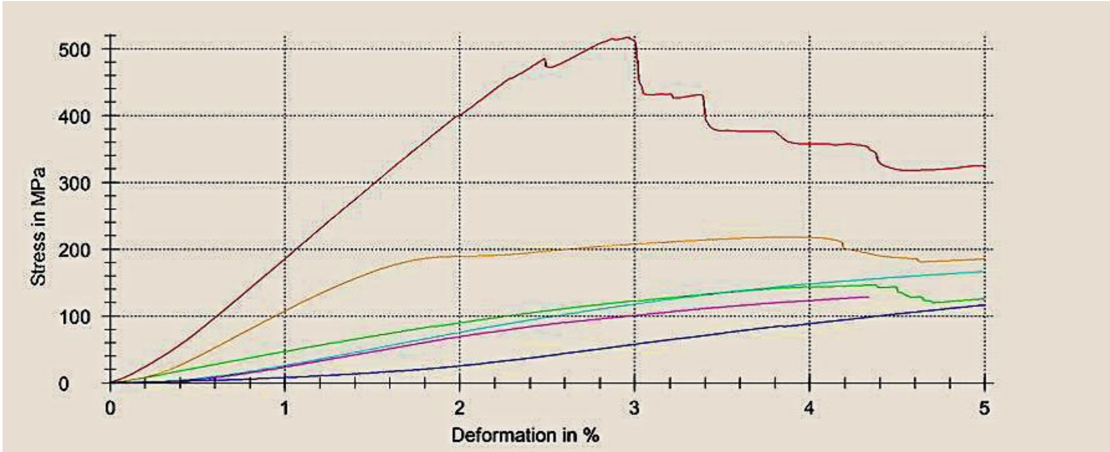

Figure 11: Stress versus deformation plots for Short beam bending

3.5 Shore Hardness test

The Shore-D hardness test was conducted for all the specimens as per ASTM 2240 standards and presented in Table 6. Generally carbon fibers are 20% stronger than the best glass fibers. Hence, the entire carbon laminate is inferred to have the greatest average value of hardness in the group. Amazingly the values of the G-C-G and K-C-K specimens are equal.

Table 6: Shore Hardness test results

Sl. No.	Sample name	1	2	Average
1	Full Carbon	92	91	91.5
2	Full Kevlar	84	84	84.0
3	Full Glass	87	88	87.5
4	Glass + Carbon + Glass	83	83	83.0
5	Kevlar +Carbon + Kevlar	83	83	83.0
6	Carbon +Glass + Carbon	89	89	88.5

4. Conclusions

The current experimental effort sheds information on how various combination materials behave under various testing circumstances.

The K-C-K hybrid composite combination offers the highest impact bearing capability, according the findings of the swing impact test. The cost of this material is unquestionably lower than the clean carbon composite since two layers of Kevlar fibre are employed on either side of the carbon fibres. Since safety is paramount and impact force is slightly higher, this material can be used to create bike riders' helmets.

The results of the interlaminar shear stress test, the tensile test, and the flexural and flexural tests show that the G-C-G hybrid composite has a large amount of strength to sustain the impact load. In these tests, this combination competes with pure carbon composite, which is thought to be the best. This composite can therefore be utilised to produce inexpensive composites that can bear impact forces at moderate speeds. This composite is particularly inexpensive since it contains two layers of glass. The worker's helmet can be made from this material.

Despite having the highest Shore-D hardness rating, carbon laminate is not the most economical material. Different combinations of composites can be chosen for different applications depending on the requirement and cost of the product.

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