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BALLISTIC PERFORMANCE OF POLYCARBONATE COMPOSITES: A REVIEW

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Abstract: Polycarbonate (PC), a transparent polymer, is widely recognized for its remarkable ability to resist ballistic impacts, preventing penetrations and punctures. The amount of die is consistently the predominant factor affecting its performance. The review provides a comprehensive view of the mechanical properties and potential applications of PC matrix composites, evaluating their performance, including V50 speed limit and energy absorption through ballistic testing. Finally, applications from the last 5 years are described to show the current state of this composite material.
Keywords: polycarbonate, composites, ballistics, armor.

INTRODUCTION

Recent research and development focused on the area of armor, dedicated to the selection and analysis of materials, has led to the discovery of properties with great potential for ballistic applications. Expertise in ballistic studies has used advanced materials to achieve specific performance, meeting the rigorous requirements in the precise selection of these materials. Rigid armor systems are widely used to protect against high-speed impacts. Different forms of body armor have been developed to improve ballistic performance in these conditions. An example is fiber-reinforced PMC, recognized for its high energy absorption capacity, due to its strength and rigidity.(BHAT et al., 2021).Advanced composite materials, such as aramid fiber, are recognized for their high tenacity, playing a crucial role in projectile energy absorption. An important characteristic of these composites is the dependence of their elastic moduli and natural frequencies on temperature, which can be adjusted to obtain the desired properties of the material.(SOYKASAP; COLAKOGLU, 2010).This adjustment can affect the ballistic properties of the composite. Fabrics with high resistance fibers, such as aramid (YANG et al., 2021)(RUBIO et al., 2019),UHWMPE(MAWKHLIENG; GUPTA; MAJUMDAR, 2021)they are more effective materials for dissipating projectile energy. Currently, thermoplastic composites have received attention, but the commonly used thermoplastic matrix, such as PC and PP, generally has a higher melting point than UHMWPE, making its application more difficult. Aramid fibers have been widely used in thermoplastic composites due to their good thermal stability. In the present study, PC will be reviewed as a potential matrix for ballistic composites, evaluating its performance such as the V50 ballistic limit and energy absorption through specific tests.

GENERAL ASPECTS

BALLISTIC ARMOR

The protection of the human body against various threats, such as sharp objects and combat projectiles, has roots in the history of humanity. Over time, different civilizations have used a variety of primitive materials, such as animal skin (leather), wood, stones, copper and steel, to protect themselves against various dangers.(ABTEW et al., 2019).Furthermore, fabrics and laminates made from synthetic and natural fibers such as linen, cotton, natural coconut fibers, silk and nylon have played an important role not only in the manufacture of clothing but also as protective materials against various threats, including applications ballistics(LIGHT et al., 2020).During the Middle Ages, suits of chain armor were employed in different ways for protection. However, current military operations, technology-driven warfare tactics and the presence of modern weapons and ammunition in urban areas demand the development of advanced ballistic protection systems. These systems must be lightweight, resistant to damage, flexible and capable of absorbing a significant amount of energy(ABTEW et al., 2019).The revolution in the modern generation of ballistic vests began in the late 1960s following the development of new synthetic fibrous materials with high-performance anti-ballistic capabilities. (ABTEW et al., 2019).In recent decades, the demand for high-strength and stiffness materials has increased substantially due to the increasing application of PMCs in various technical sectors. However, it is important to highlight that composite structures used in defense, maritime, automotive, civil and aerospace applications can also be subject to localized impacts from projectiles. These impacts can result in deformations, partial or total penetrations, depending on several factors, such as the type of material, the thickness of the compound, the mass and speed of the projectile, as well as its geometry. (ABTEW et al., 2019).

POLYMERIC MATRIX COMPOSITES

A composite is a material made from the joining of two or more materials used in which there is a synergy effect of properties, that is, it presents properties superior to the properties of each of the constituent materials. (HSISSOU et al., 2021).Composite materials are made up of two or more different phases: a matrix, which is continuous, and another phase, which is called the dispersed phase, which is made up of particles on a macro, micro or nanometric scale. The matrix, in turn, is in greater concentration, therefore, it involves the dispersed phase as exemplified in Figure2.1.The properties of composites are determined by the properties of the constituent phases, their relative proportions and the geometry of the dispersed phase. Within this context, the geometry of the dispersed phase refers to the configuration, dimensions, distribution and orientation of the particles.

PMCs are a specific type of composite in which the matrix, the continuous component of the material, is made from a polymer. In this type of composite, the polymer matrix surrounds or encapsulates reinforcing materials, such as fibers or particles, with the aim of improving or modifying the mechanical properties of the material (RAMAWAT et al., 2023).Common examples of reinforcing materials include glass and aramid fibers. The most used are in the form of fiber, whose charge has a large aspect ratio in relation to the matrix, and can be continuous or random. Those reinforced with particles, in general, have approximately equal dimensions. Therefore, they are categorized according to the type of matrix into three distinct classes: organic, mineral and metallic. Organic composites include cardboard (with resins and cellulose fibers), laminated tires (combining rubber, steel, organic resins, glass fibers) and reinforced plastics (with resins and short fibers)(HSISSOU et al., 2020).In the category of mineral composites, there are concrete (with cement, sand and additives), carbon-carbon composites (composed of carbon and carbon fibers) and ceramic composites (which contain ceramics and ceramic fibers), (BOłTRYK; KRUPA; PAWLUCZUK,2018). Finally, metallic composites (such as aluminum/boron fibers and aluminum/carbon fibers) complete this classification. The matrix of a composite material, regardless of the scale, nano or macro, must meet certain points, such as maintaining homogeneous orientation and spacing of the reinforcement in the medium, effective transmission of shear forces and the provision of protection against surface damage to the reinforcement(BRO; MENDES, 2004).The interest in working with polymeric materials is that they meet these requirements, are easy to process and also have a lower cost compared to metallic and ceramic materials. The raw

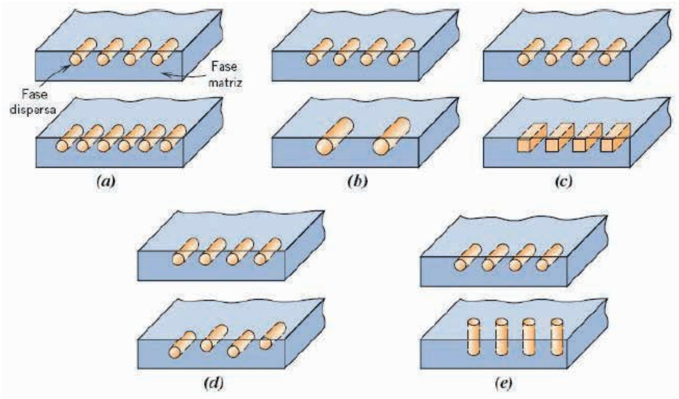

Figure 2.1: Schematic representations of the various geometric and spatial characteristics of dispersed phase particles that can influence the properties of composites: (a) concentration, (b) size, (c) shape and (e) orientation. With permission from CALLISTER JR.; RETHWISCH, 2014.

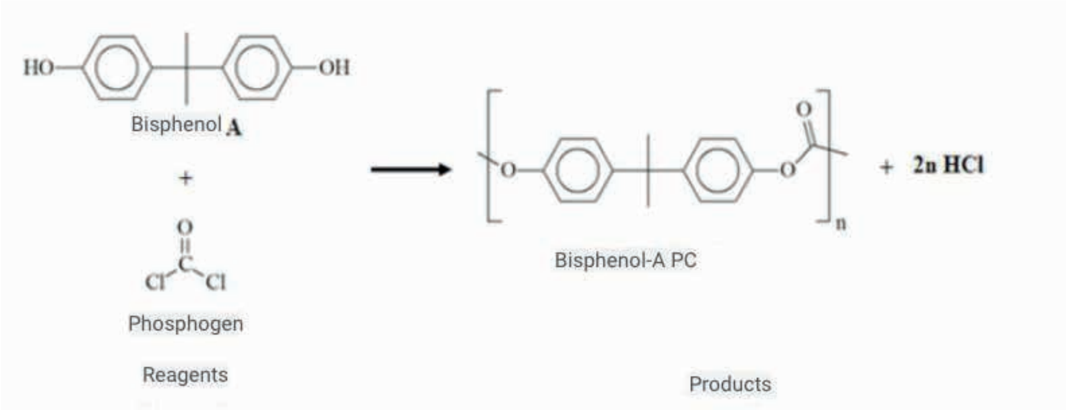

Figure 2.2: Example of aromatic PC (BPA-PC). Source: With permission by CANEVAROLO,2010.

Property	Value	Unit of measure
Density	1, 2	(g/cm3)
Resistance traction	55 – 75	(Mpa)
Stretching at break	2 – 120	(%)
Limit of flow	50 – 65	(Mpa)
Modulus of elasticity	2400	(Mpa)
Resistance to the impact 23°C	35	(KJ/cm2)

Table 2.1: Properties of Bisphenol-A Polycarbonate.

Source: (PAKULL; GRIGO; FREITAG, 1991) (NAYLOR, 2004).

material for the production of a polymer is the monomer, that is, a molecule with one (mono) repeating unit (mer). Depending on the type of monomer (chemical structure), the average number of mers per chain and the type of covalent bond, polymers can be divided into three large classes: Plastics, Rubbers and Fibers.(CANEVAROLO, 2010). Polymers are generally categorized into two groups: thermoplastic and thermoset, based on their fusibility and/or solubility properties, which determine distinct technological processes. In the case of thermoplastics, whether they have a linear or branched structure, they make it possible to perform rework after processing, since they can be melted by heating and solidified by cooling. This means that thermoplastics allow them to be recycled chemically or mechanically. Examples of thermoplastic polymers are PC, PVC, PMMA, etc. Thermosetting polymers, also known as thermosets, are resins processed in the form of a pre-polymer (before curing, without cross-links) with high fluidity, which are molded while still in their fluid state and, through reaction with an initiating/hardening agent, form cross-covalent bonds, acquiring mechanical resistance in the process and becoming an infusible polymer(CANEVAROLO, 2010) (MONTICELI et al., 2021). Examples of thermosetting polymers are epoxy and phenolic resins. Depending on the polymerization conditions of each monomer, not all chains reach a specific length, resulting in different molecular weights for the polymer. This is relevant because, for the same polymeric structure, the properties of polymers evolve gradually with increasing molecular weight (g/mol), becoming less noticeable when these weights reach or exceed the order of magnitude of g/mol.(BRO; MENDES, 2004). In other words, as the molecular weight increases, some polymer properties such as viscosity, softening point, tensile strength, impact resistance also increase. Another important element is the degree of crystallinity of the polymers. No polymer is completely crystalline, this means that polymers form solids with both amorphous and crystalline phases. The amorphous regions contribute to elasticity, flexibility, and can also cause changes in the physical properties and resistance of the polymer to solvents. It is important to highlight the analysis of the thermal performance of the polymer. Through this analysis, it is possible to obtain essential first-order thermodynamic information, such as melting and crystallization, and second-order, such as the glass transition temperature and secondary relaxations associated with crystalline and amorphous phases. Commonly, this analysis is done using a thermal analysis technique called Differential Scanning Calorimetry or Differential Scanning Calorimetry (DSC). DSC analysis works by comparing the amount of heat absorbed or released by a sample relative to a reference as the temperature changes. Generally, heat absorption or release occurs with physical or chemical changes in the sample, such as melting, crystallization, glass transitions, chemical reactions, or degradation. One example is photodegradation, an important reaction for polymers exposed to sunlight. (CANEVAROLO, 2010).In the case of amorphous polymers, it is crucial to investigate the primary relaxation, also known as α relaxation or glass transition region (Tg). This transition is the result of molecular movements in segments of the polymer backbone. Tg occurs within a specific temperature range and is directly affected by the composition, flexibility of the molecular chain, molecular weight, presence of plasticizer, degree of crosslinking and degree of crystallinity of the polymer.(CASSU; FELISBERTI, 2005).

POLYCARBONATE

PC is a special class of polyesters also resulting from the reaction of carbonic acid derivatives with dihydroxylated compounds. PC has the carbonate functional group in its main chain and can be divided into aliphatic and aromatic PCs. Aliphatic PCs, which can be found in the form of open chains or open chain-like cycles, are of low commercial importance due to their low melting point characteristics and low thermal stability. (FUKUOKA et al., 2019).Aromatic PCs are characterized by having aromatic nuclei in the main chain structure, in addition to carbonate groups(MIRZAEE, 2018).In its manufacture, different types of bisphenols can be used, however, in the production of engineering plastics, BPA, or diphenyl carbonate PC is commonly used (Figure2.2).

The carbonate unit is generally derived from interfacial polycondensation reactions between Bisphenol-A and phosgene gas, forming the characteristic structure of polycarbonate. According to NYLOR (2004), the physical properties of BPA-PC are characterized by a molecular weight ranging from 20,000 to 200,000 g/mol; They are generally amorphous, but can be crystallized through various techniques, such as heating to high temperatures, treatment with solvents, stretching of fibers or films, or even through mixtures with plasticizers and other polymers. Its melting temperature can be measured at around 275 °C and Tg at around 150 °C. The Tg is considered high, compared to other thermoplastics such as PE, which has a Tg of 100 °C and poly (butylene terephthalate) which has a Tg of 40 °C. The high Tg is noted by the slowdown in the movements of the chain segments, which include the aromatic rings and the extensive repeating units. Its preferred solvents are chloroform, cis-1,2-dichloroethane and tetrachloroethane.

In addition to these, several other advantages of PC materials can be listed, such as dimensional stability, high impact resistance, lightness and optical clarity. (KRAUSZ et al., 2021). Composites using PC as a matrix can include materials such as glass fibers or other additives to further improve their physical properties. The Table 2.1exposes some of the properties of BPA in numbers.

POLYCARBONATE: BALLISTIC IMPACT PROPERTIES

WALLEY et al.(2004) studied the impact behavior of PC boards and PC and glass laminates, joined by polyurethane adhesive film, as a function of temperature variation. They considered the formation of cracks and chips inside the PC during the impact. The ballistic impact of steel balls, at a speed of 350 m/s, against laminates composed of PC and glass joined by a PU film, results in intense fragmentation of the glass. This impact generates radial and circumferential cracks, as illustrated in Figure2.3.Reducing the temperature results in a decrease in the number of cracks in the glass, contrary to the expectation that decreasing the temperature makes the glass more fragile. This phenomenon occurs due to the fact that, as the temperature decreases, the PC/PU composite becomes more rigid, leading to greater delamination. This effect is indicated by an arrow in Figure 2.3 (d).

SHIM et al. (2015),improved the ballistic limit (V50) to 973.8 m/s by combining PC and multilayer defense film with reinforced glass. This result met the ballistic limit of NIJ-STD-0108.01 (V50: 838 ± 15 m/s) (STANDARD, 1985). This limit evaluates a material's ability to provide ballistic protection by determining the speed at which 50% of impacts result in complete penetration and 50% in partial penetration. V50 is the speed at which the material has an equal chance of resisting the impact of the projectile or being

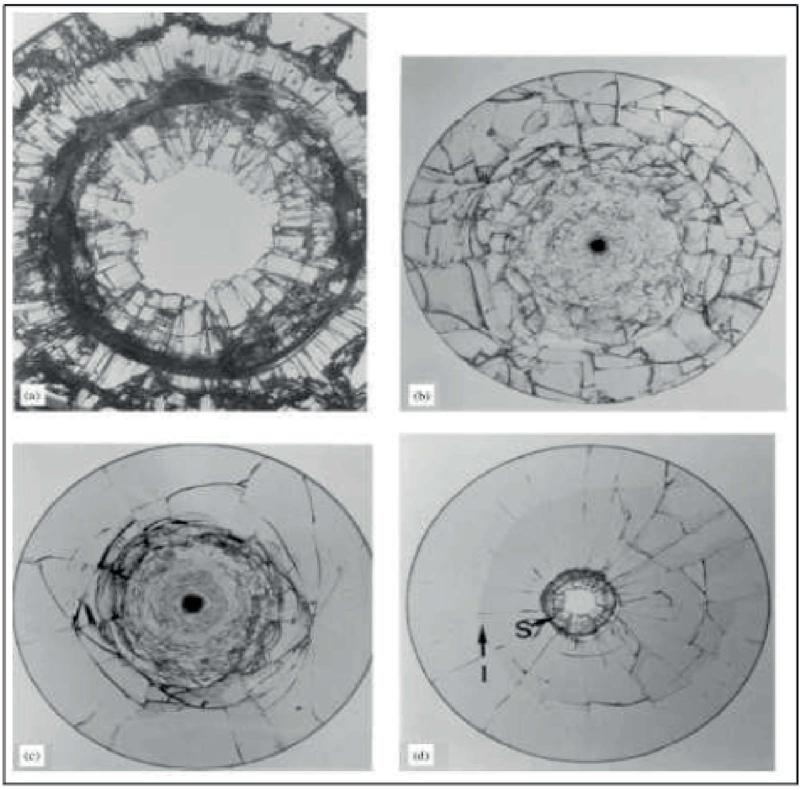

Figure 2.3: Impact of a steel ball on a laminated disc at a speed of 350 m/s: (a) disc with 50 mm diameter at a temperature of -25ºC; (bd) disk with 152 mm in diameter at temperatures of (b) 20 ºC; (c) -28.5 ºC and (d) -34 ºC. Reproduced with permission of WALLEY et al.,2004.

Sl.no	Code of sample	Proportion of PC (%p/p)	Area density (Kg/m^2)	Midsize SAP Cost	Approximate cost savings (%)
1	Controle-AW (24)	0	5.04	26.389	-
2	AW (20)+PC (1)	13	4,83	22.164	16,0
3	Controle-A-UD (20)	0	4,60	27.501	-
4	A-UD (15)+PC (2)	27	4,71	20.972	23,7
5	A-UD (12)+PC (3)	41	4,65	17.020	38,1

Figure 3.1: Calculation of material costs for different SAP configurations. Source:(BAJYA et al., 2021).

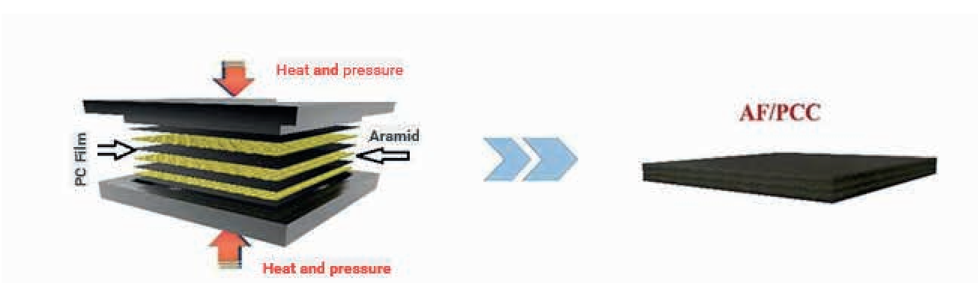

Figure 3.2: Preparation scheme for AF/PCC laminates. Source:(HAN et al., 2023).

pierced by it.

STATE OF THE ART

In the literature review, it is evident that PC is a material investigated since the beginning of the 19th century, when it was designed and developed to achieve greater thermal stability and satisfactory mechanical resistance. The SCOPUS database reveals scientific productions from the late 1970s onwards, focusing on polymer matrix composites, with PC being one of the main polymers. The collection presents 1330 documents(SCOPUS, 2023).Although there were only two publications in 1978, the topic began to gain prominence, reaching 67 articles produced in 2021. These numbers, still relatively low, indicate a gradual growth of PC matrix composites, in contrast to other polymers, such as PU, which accumulated 8506 publications in the same period. Over the past five years, 320 articles have been published on PC composites, of which approximately 75% focus on materials science.(SCOPUS, 2023).

MECHANICAL AND BALLISTIC PERFORMANCE IN POLYCARBONATE COMPOSITES

BAJYA; MAJUMDAR; BUTOLA (2022),performed a comparison of the ballistic performance of different fabrics, such as para-aramid, UHMWPE and PBO (poly para-phenylene-2,6-benzobisoxazole). It was shown that friction between the threads played a crucial role in the ballistic performance of these fabrics.(CLAUS et al., 2020).BAJYA et al.(2021) in another work, showed that PC sheets can be used to replace expensive high-performance fabrics in the hybridization of soft armor panels (SAPSs). The main idea behind hybrid panels is to make the best of each material to meet the needs of the project in question. With this understanding, the authors adopted a design strategy hybridizing para-aramid and UHMWPE materials, and PC sheet to develop the SAPs. The Table, represented by Figure3.1,shows the calculation of the cost of these materials for the manufacture of SAP. The PC boards managed to replace up to 41% of high-performance materials, resulting in a reduction in the costs of materials used in the armor of 38%, being the best result obtained among the samples. This study revealed the prospect of replacing high-cost fabrics with more affordable materials, which would not only reduce costs but also improve the ballistic performance. It was conducted a study related to the incorporation of PC in AF/PCC, aiming to improve ballistic protection due to the notable impact resistance presented by PC. Aramid/PC flat fabric composites were produced with different matrix proportions, ranging from 30%, 25%, 20%, 15%, 10% by weight and 0% by weight (neat fabric) and were named as AF/PCC -30, 25, 20, 15, 10, NF, respectively. The study included analysis of the ballistic limit and energy absorption capacity through ballistic tests. The effects of matrix composition on the ballistic resistance and damage mechanisms of the aramid/ PC composite were thoroughly examined, combining quasi-static testing and observation of the composites after impact, resulting in a detailed and comprehensive analysis.

The AF/PCC composites were produced using a hot-pressing machine with vacuum molds, employing layers of plain aramid fabrics and PC films of dimensions 300 mm × 300 mm. The aramid and PC films were arranged in alternating layers in a metallic mold.

as illustrated in Figure3.2,and the metal mold was then inserted into the hot-pressing machine using vacuum. The specimens for the quasi-static tests were obtained by cutting from AF/PCC laminates, using a high-speed water jet machine. Five specimens were tested for tension, flexure, interlaminar shear strength (ILSS), compression and mode I interlaminar fracture toughness (GIC). As for analysis, through the tensile test, all samples demonstrated a deviation from the elastic behavior in the stress-strain curve as shown in Figure 3.3 (a). This curve was evaluated in three distinct regions, which the authors called crimp, linear pre-peak and linear post-peak. In the crimping zone, a smaller amount of matrix resulted in lower resistance at the interface between the matrix and the fiber, preventing load transfer from the matrix to the fiber. As the fiber was stretched, the tension increased linearly as the linear pre-peak region expanded. With larger amounts of matrix, there was a rapid transfer of load to the fiber, resulting in a steep slope in the crimp zone. Subsequently, the slope of the curve changed as the interface between the fiber and matrix ruptured under tension (Figure3.3(B)). However, as the amount of matrix increased, the impregnation between the matrix and the fiber intensified, resulting in stronger interfacial properties between them.

Analyzing the flexion, to HAN et al. (2023),the higher the matrix content, the higher the flexural strength and the higher the flexural modulus, indicating high stiffness (Figure3.4d). Otherwise, when there is a lower matrix content, the flexural resistance decreases, causing the stiffness of the composite to also decrease. This increase or decline is related to the impregnation of the fiber in the matrix, which improves or worsens the interfacial bond. Depending on how much less the matrix content is, the flexural strength drops and the material may show cracks. The stress-strain curve of the AF/PCC changed linearly, showing that the higher the matrix content, the greater the slope of the curve, indicating greater flexural stiffness of the material (Figure3.4w).

Fiber-reinforced polymer matrix composites can slow down projectile advancement by absorbing its kinetic energy through shear deformation. Therefore, increasing the matrix content increases the stiffness making the slope greater, resulting in a rapid increase in load. Those behaviors are evidenced in Figures 3.5(e) and (f). Otherwise, the material becomes more prone to rupture inside. HAN et al. (2023)observed that as the matrix content decreased, the compressive strength of AF/PCC increased. The compressive strength of AF/PCC-10 reached the highest value (1018.56 MPa), while that of AF/PCC-30 was lower, reaching only 759.54 MPa, as shown in Figure3.6(H). This disparity can be explained by the reduction in the amount of matrix, which reduced the thickness between the layers of the material, facilitating the sliding of the fibers, thus allowing them to fit together more efficiently under the applied compressive load. This explanation is related to the optimization of the properties of the composite, aiming to improve its mechanical resistance, taking advantage of the interaction between the fibers and the matrix.

Fracture toughness in mode I (opening or tensile mode) is the material's ability to resist the propagation of cracks and was also investigated by the authors, HAN et al. (2023). As shown in Figure 3.7(a), the higher matrix content affected the load values at which the crack initiated and propagated. Evidently, the fracture toughness at the initiation and propagation of AF/PCC in Figure3.7(b) exhibited a decreasing trend, which indicated that the composites were more prone to failure with decreasing matrix content.

In addition to evaluating mechanical properties, ballistic tests are also important for the performance of the material. The determination of the ballistic limit and the BFS test in accordance with NIJ-0101.06 (STANDARD, 2008) are favorable tests for

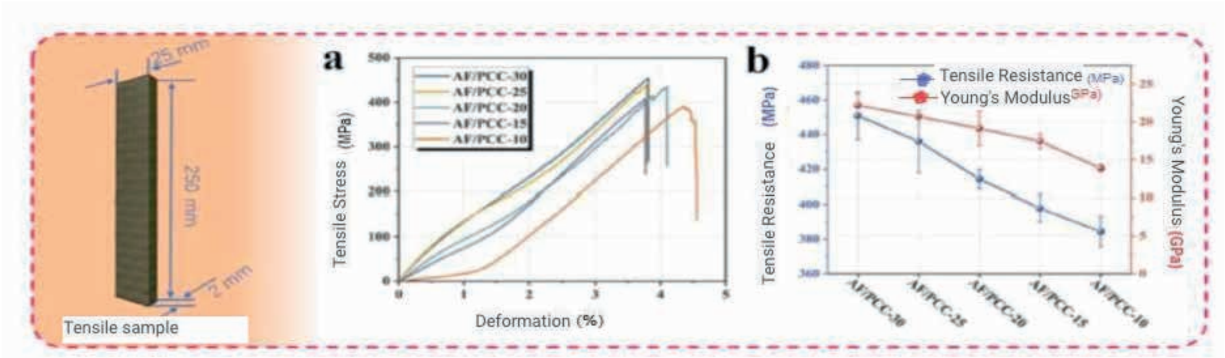

Figure 3.3 Tensile properties: (a) Stress-strain curves and (b) tensile strength and Young's Modulus (Adapted by the author). Source:(HAN et al., 2023).

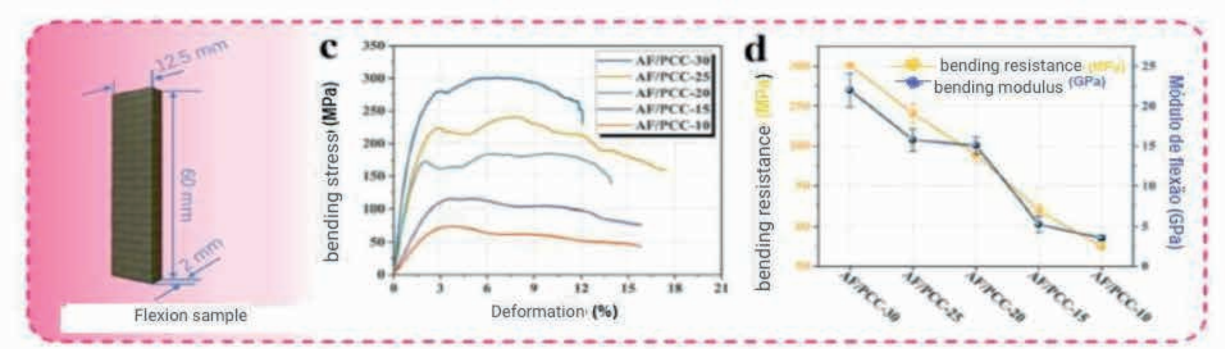

Figure 3.4 Flexural properties: (c) Stress-strain curves and (d) flexural strength and flexural modulus (Adapted by the author). Source:(HAN et al., 2023).

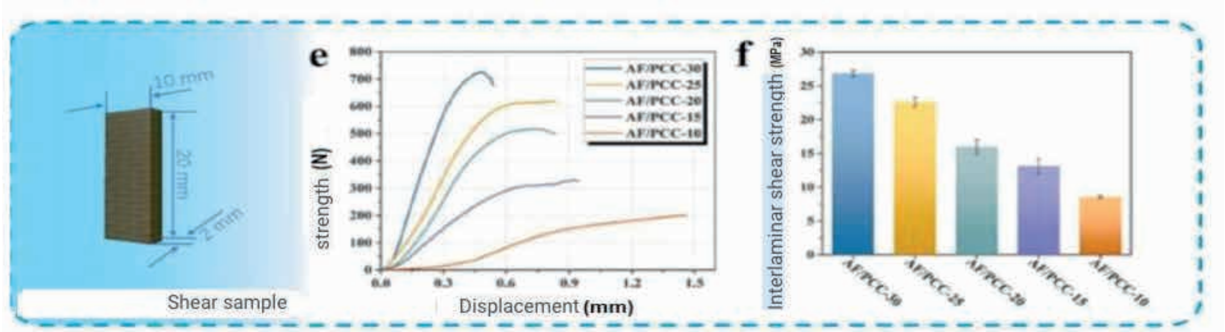

Figure 3.5 Shear properties: (e) Load-displacement curves and (f) Shear strength (Adapted by the author). Source:(HAN et al., 2023).

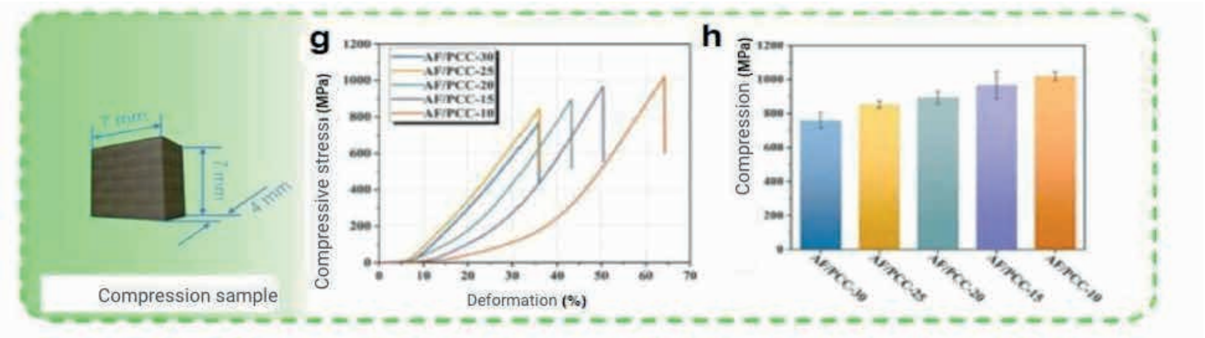

Figure 3.6: Axial compressive properties of the AF/PCC stress-strain curves (g) and compressive strength (h) (Adapted by the author). Source:(HAN et al., 2023).

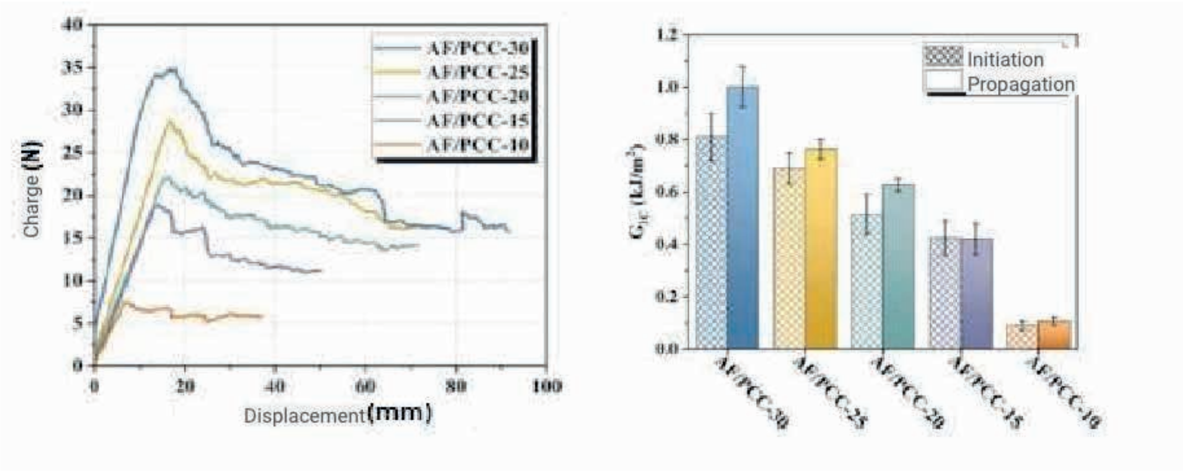

Figure 3.7: (a) Load-displacement curve and (b) fracture initiation and propagation toughness of AF/PCC samples (Adapted by the author). Source:(HAN et al., 2023).

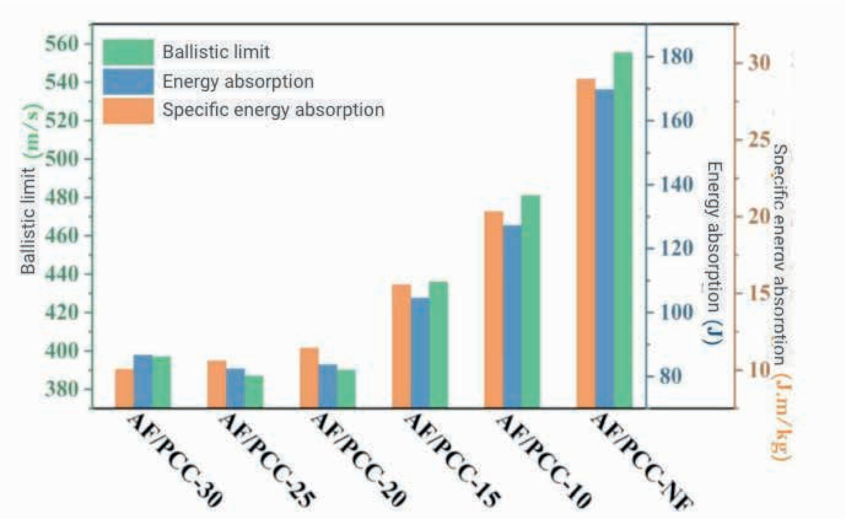

Figure 3.8: Ballistic performance of AF/PCC: V50, energy absorption and absorption specific energy (Adapted). Source:(HAN et al., 2023).

performance analysis. The BFS (Back Face Signature) test is performed to measure the piercing resistance of armor. In this test, the back face of the armor system is kept in direct contact with plasticine simulating the human body, which is plastically deformed to capture and measure the depth of trauma left after the non-piercing ballistic impact. To determine the V50, the materials undergo ballistic tests involving at least 10 shots. According to HAN et al. (2023),By varying projectile velocities, three bullet holes and three partial penetrations were recorded within a narrower velocities range, typically around 38 m/s. V50 was determined as the average of these six speeds. HAN et al.(2023) reported that the V50 ballistic limit and energy absorption of laminates were the most direct and important data from AF/PCC, as seen in Figure 3.8 and Table3.1.Analysis of the V50 revealed a upward trend from AF/PCC-30 to AF/PCC-NF, although with slight fluctuations in AF/PCC-30, AF/PCC-25 and AF/PCC-20; 397.10 m/s, 387.90 m/s, 390.00 m/s respectively. When the matrix content was reduced below 20%, a rapid increase in V50 was observed. Compared with AF/PCC-20, the V50 values of AF/PCC-15, AF/PCC-10, and AF/PCC-NF increased by 12.02%, 23.33%, and 42.44%, respectively. This trend was also reflected in energy absorption, which increased with matrix contents below 20%, reaching the maximum point at AF/PCC-NF (555.50 m/s). The presence of the matrix limited the displacement of the strands, preventing them from fully stretching to absorb energy before breaking. Furthermore, the matrix had an effect on reducing the BFS measurement.

HAN et al.(2023) observed that compressive strength increased as the matrix content decreased, providing a greater initial compressive strength for AF/PCC, which resulted in a notable improvement in V50 and energy absorption values. This behavior was also observed in the work of TIRILLÒ et al.(2017). Both flexural strength and elastic modulus also played a significant role in the V50 and energy absorption values of the AF/PCC composite. In the case of non-fibrillated composites (AF/PCC-NF), the fibers effectively played a role in tensile failure and energy absorption, resulting in the highest V50 values for this type of composite. In order to evaluate the energy absorption efficiency of the desired material, the specific energy absorption (SEA) was calculated based on the equation of the difference between the initial energy of the projectile and the remaining energy (DAVID; GAO; ZHENG,2009).

$$(3.1) SEA = \frac{\frac{1}{2}m(V_{50}^2)}{areal\ density}$$

Observing the data in the Table3.1,it was observed that the AF/PCC-NF composite demonstrated the highest value of (SEA). With the presence of the matrix, the SEA of AF/PCC-10 was recorded at 20.33 J x m²/kg, which represented a reduction of 42.45% compared to AF/PCC-NF. This indicates that the presence of the matrix had a significant impact on the energy absorption capacity of the aramid fabric.(HAN et al., 2023). The SEA of AF/PCC-15 was measured at 15.56 J x m²/kg, resulting in a 30.66% reduction compared to AF/PCC-10. These results indicate that the increase in matrix had a contrary influence on the ballistic property of the AF/PCC. As the matrix content increased, the SEA of the other composites was similar. This suggests that by increasing the amount of matrix to a certain extent, the energy absorption capacity of AF/PCC reached a stagnation point, and further increases in matrix content would result in a negative influence on this capacity. In other words, a further increase in matrix content would not provide a significant improvement in the energy absorption capacity of the composite. As mentioned previously, the

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Samples	Density of area (kg/m^2)	Limit ballistic(m/s)	Absorption In energy (J)	SEA (J×m2/kg)	BFS (millimeter)
AF/PCC-NF	5.86	555.50	169.72	28.96	37.90 ±3.68
AF/PCC-10	6.26	481.00	127.25	20.33	22.25 ±1.62
AF/PCC-15	6.72	436.90	104.55	15.56	22.00 ±2.62
AF/PCC-20	7.31	390.00	83.66	11.44	Drilling
AF/PCC-25	7.76	387.90	82.37	10.60	Drilling
AF/PCC-30	8.62	397.10	86.68	10.06	Drilling

Table 3.1: AF/PCC ballistic impact results.

Source: Adapted from(HAN et al., 2023).

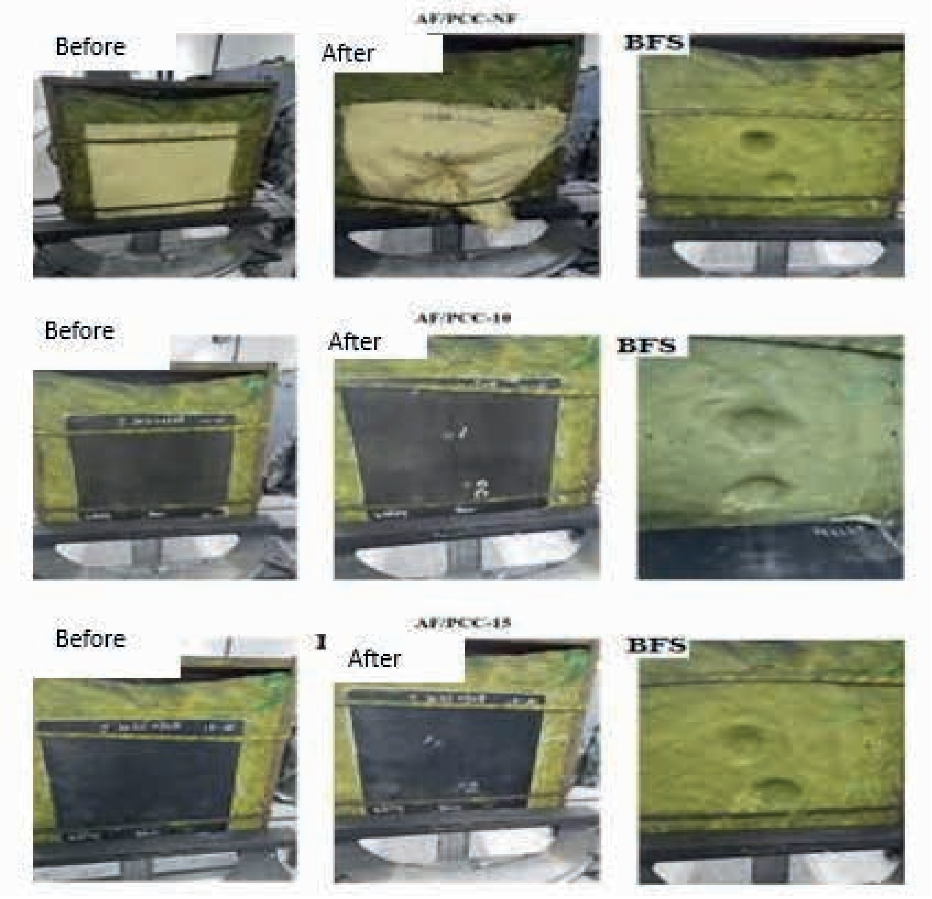

Figure 3.9: The clay deformation configurations after the BFS ballistic test of the AF/PCC composites. Source:(HAN et al., 2023).

authors investigated BFS in accordance with NIJ-0101.06. As shown in Table3.1,the AF/PCC-NF sample showed higher BFS. However, with the presence of the matrix, the BFS of AF/PCC directly decreased. The BFS of the AF/PCC-10 and AF/PCC-15 samples were reduced to half the BFS of the clean tissue sample. This indicates that the presence of the matrix can effectively reduce BFS. Figure 3.8 shows the deformation configurations after the ballistic tests. For samples AF/PCC-20, 25, 30, due to the high matrix content, the intense resistance at the interface between the matrix and the fiber restricted its movement, resulting in perforation during the ballistic impact. This restriction of fiber movement during impact affected the material's ability to deform and absorb the projectile's energy.

CONCLUSION

The parameters for an effective system are energy absorption, ballistic limit and recoil depth. Therefore, works dedicated to investigating PC aspects and their performance in the face of ballistic impact were analyzed. According to the literature, this analysis allows us to infer that the use of PC sheets as a substitute material for high-performance fabrics can reduce production costs by up to 38% without compromising ballistic performance. It is also possible to reduce BFS compared to using tissue-based scaffolds. As for PC used as a matrix for a fiber-reinforced composite, the literature shows that the performance is positive. As for mechanical properties, when matrix content increases, flexural and shear resistance and fracture toughness increase, indicating high stiffness to the material.

When it comes to ballistic properties, the presence of the matrix can join the wires to reduce the BFS of the composites, consequently reducing non-penetrating damage caused by projectiles. As for the ballistic limit (V50), composites with low matrix content caused a rapid increase in V50. Thus, with the progress and development of science, technologies are increasingly diversified, seeking to improve materials to combine better performance and better costs.

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