Post Impact Behavior and Compression After Impact Properties of Polymers and Their Composites—A Review

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Abstract Understanding the post-impact properties are essential while designing a new material system. Serviceability and sustainability are matters to protect the assembly from accidents since transportation and assembly operations experience many micro-damages in the material system. Researchers carried out several experiments to understand the post-impact performance of the laboratory scale specimens. Upon conducting the low velocity and other impact studies, the tensile, compression after impact (CAI), and related static properties have been measured and reported by the researchers. Even though the exploration is wider to analyze in the literature, a categorization is needed to proceed the further research in this field. Challenges are classified as conducting experiments, measuring the data, visualizing the results, data correlation and interpretation. Present review also contexted in a similar fashion to create a deeper insite about the post-impact characteristics.

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1 Introduction

As impact damages are unavoidable in different applications, so it becomes inevitable and essential to the study of after impact analysis for the safety of structures. Following literature summary shows the after-impact studies performed on different composites. Majority of authors have focused their studies on the compression after impact (CAI) for different configuration of materials. The structural load bearing capacity is severaly reduced due to the micro-cracks induced during the low velocity impacts, resulting in catrascopic failure. Hence it is most essential to understand the post impact behaviors before installing a new material into a structure. Researchers have explored the change in materials behaviour after impact as a function of material type, loading nature, time etc.

Fiber reinforced composites are sensitive to impact and thereby reduces the mechanical properties especially compression performance after impact. To study this author performed the compression after impact (CAI) test on the fiber reinforced composites. Local buckling and shear failures are observed in compression test. As impact energy increases the compressive strength and failure strain decreases due to impact damage. Due to impact the damage area increases resulting in reduced bearing area and in turn reduction in bearing capacity. The impact damage sharply reduces compressive strength and stiffness of the material, and the residual compression strength and stiffness were decreased to 62.25 and 76.6%, respectively (Hongji et al. 2019).

1.1 Constituent Type as Factors

Several reports are in literature to characterize the significance of constituent types especially the type of reinforcement on the post-impact behaviours. The load distribution mechanism is one of the key factor to study when the post-impact in concern. An Investigation of unstitched and stitched ([02/902] S-type A and [902/02] S-type B) laminated samples is done by applying low velocity impact energies 1–8 J. After impact flexural tests using three-point bending test are carried out. The flexural properties are observed to be greatly affected due to impact. Due to stitching in direction parallel to fiber direction some damage may be induced which revealed by reduction in flexural strength for both stitched and unstitched specimens (Francesconi and Aymerich 2018). A conclusion arrived as to sustain higher post-impact strength, the secondary stitching can be introduced as normal to the fiber impregmated direction.

Low velocity impact response of 3D integrated-woven hybrid sandwich composite panels is studied in this paper. Damage in terms of compressive strength loss due to impact is interpreted. The hybrid sandwich showed lower impact index but residual strength is observed to be higher than the glass/epoxy composites. Two different core thicknesses and three different pile thickness are used for preparation of samples. Author reported that as piles thickness reduces the maximum impact force whereas as pile density increases peak load also increases.

Impact and compression properties are studied for woven composites after thermal aging degradation at 180 degree and for different days. The compression after impact properties are greatly reduced after thermal aging at 32 days. Interface damage and matrix degradation are the important factor responsible for the degradation in properties. Damage evolution study by FEA revealed brittle and progressive failure modes for unaged and aged samples respectively and author expects that, this might be due to stress plateau in stress–strain curve (Cao et al. 2018). Un treated woven flax fiber reinforced PLA composites were prepared through compression moulding technique. Low velocity impact test was conducted on the composite samples followed by the after impact behavior evaluation. The test results were compared with the carbon/epoxy laminates. The comparison revealed the advantages of flax/PLA composites over carbon/epoxy laminates in view of the energy absorption and normalized residual strength. The flax/PLA composites possessed higher energy absorption than the carbon/epoxy laminates due to the absence of delamination. The only failure mode noted in the flax/PLA composites was fiber breakage which was having no relation with the energy absorption and residual strength. Besides, carbon/epoxy laminated suffered due to the delamination and thus the residual strength was pulled down.

1.2 Role of Hybridization

Another study, an external hybrid patches of glass/Kevlar are used to repair the damaged composite on low velocity impact and the quasi-static tensile test response is studied after impact response. Different impact energies are used for the study and it is observed that hybridization influences the energy absorption. Intra-ply hybrid patches showed better impact properties (Andrew et al. 2019). In this, author developed a novel sandwich panel with hybrid skin layers and core made of foam. The skin is hybridization of woven glass and wire net in an epoxy matrix. Compression after impact tests is performed to determine residual properties after impact. Author reported great enhancement in impact and residual properties. In impact, three damage modes viz. breaking, delamination and foam cracking, while in compression after test two damage modes viz. buckling and delamination are observed. Digital image correlation and SEM are used for damage mechanism analysis (Wan et al. 2020).

The pile hybridization reduces the core stiffness which resulted in reduction in maximum impact force (Mirdehghan et al. 2020). E-glass/S-glass/Epoxy hybrid sandwich with PVC as core material is fabricated. Different stacking sequence and impact velocities are used for this study. Post impact flexural strength is measured.

The author observed that the carbon fibers in the face sheet increased the peak load and impact energies. It is also observed to increase the flexural strength of composite (Özen 2017). Author has investigated the compression after low velocity impact (CAI) properties of stitched and unstitched composite. Samples with hand stitching and machine stitching are prepared. According to ASTM D7136 test were conducted and ASTM D7137 is used for compression after low velocity impact test. Optical microscope and digital image analyzer software is used for damage analysis. Use of mechanical needle caused filament breakage and that affected the CAI and damage sizes. Author observed that the stitched specimens have higher impact strength than unstitched specimens although multi-stitched damage areas are larger. Author suggested this is because multi-stitching prevents inter-layer delamination in out of plane direction and intra-splitting of fiber in in-plane direction (Erdogan and Bilisik 2018).

Impact and after impact behavior of carbon/epoxy laminate modified with milled glass fiber are investigated in this article. Two different layup configurations viz. unidirectional (UD) and cross-ply (CP) are evaluated for different impact velocities. The residual load bearing capacity of post impacted specimens is evaluated by three point bending test. The filled samples showed higher peak force, lower deformation and lower damage the milled glass fiber prevents the crack propagation and reduces the damage. The residual flexural after impact (FAI) is obvious to decrease with increasing velocities. But filled samples show less reduction in FAI as compared to unfilled samples. Author also observed that absorption of impact energy is more in CP samples. CP filed and UD filled specimens are better for low impact energies and high impact energies respectively (Kannivel et al. 2019).

A low velocity impact property of Kevlar/basalt polypropylene composite is investigated. Two different compositions with different staking sequence are prepared. Drop weight impact tests are carried out with 25, 50 and 75 J energies. Hybrid with alternate layers of Kevlar and basalt exhibited higher impact energy absorption. These experimental results are compared with the numerical simulation done in Abaqus and found in agreement (Bandaru et al. 2018).

Low velocity impact properties of pure epoxy and epoxy/glass composites are studied this paper. The composite is reinforced with MWCNT with different weight percentages dispersed in epoxy matrix by sonication process. Considerable improvement in the impact properties is observed with addition of small percentage of MWCNT. 0.34% CNT showed highest improvement (Ranjbar and Feli 2019).

The study of microstructure and residual strength of glass fiber reinforced composite with different weaving pattern after impact is done in this paper. More plies are damaged in cross ply composite than plain-weave composite so plain-weave showing better impact properties than the cross-ply composite. However plain-weave exhibited less residual strength under high impact energy. As a conclusion author reported matrix cracking and delamination happened due to low velocity impact (Liu et al. 2020).

2 Fillers and Nanoparticles Incorporations

Fillers especially in nano-scale restrict the molecular movements in the polymeric system during strain. Most of these tiny particles have less absorption characteristics whereas the carbon nanotube kind holo structures may posses higher absorption behavior. Hence the incorporation of the these particles into the polymers or polymer composite may impart additional post impact stability.

A new material epoxy/glass Nano composite with 10 wt% Nano silica and 2.5 wt% Nafen alumina Nano fiber are fabricated using VARTM. Impact strength, energy absorbed and damage area for the two Nano fillers is compared at different impacting energies. Nano silica and alumina Nano fiber showed rigid and stiff behavior respectively, at higher impacting energy. The author reported higher pick force in Nano filled composites compared to non-filled (Kallagunta and Tate 2019).

Cast iron and with different percentage of bronze chips are used to fabricate the metal matrix composite using hot isostatic pressing. A drop weight test with loading rate at 2 m/s was performed and results are compared with bulk iron and bronze, individually. The author observed that MMCs can be used to indicate bulk material properties even with porosity of 2–8% (Şahin et al. 2019). Functionally graded carbon nanotubes laminate with different stacking sequence is studied to evaluate the low velocity impact performance of the composite. Higher impact velocity is observed to give larger deformation (Yang et al. 2018).

In contrast, Nor et al. (2019) have built natural fiber composite with dopped carbon nanotubes in various weight portions. Authors have conducted low velocity impact studies on the plain and nanohybrid composites to characterize the effect of nanofiller incorporation on the LVI and after impact properties. In LVI test, the composites incorporated with the CNT consumed less energy and produced smaller cracks compared to the another manufactured one with no nanofillers. To characterize the impact damage, the ultrasonic wave propagation imaging technique is employed. Authors have reported that a 23% increment in the after impact strength were noted with the samples prepared with nanofillers. Especially the nanocomposites produced at 10% filler addition have shown superior sustainabilities among the produced composites. Further the gain is linearly decreased with the increase in impact load is also reported in the research article.

Unlike the reviewed articles, Gliszczynski et al. (2020) experimented the CAL of the channels as similar to the previous study by applying larger impact loads. Studies were conducted at 20 and 30 J load for low velocity impact on the polymer composites. Laminated samples were groups as quasi-isotropic, quasi-orthotropic and angle ply arrangements and experiments conducted. According to the authors results the most unsafe impact would be the damage caused at corner which is perpendicular to the web. The compression after impact properties of the corner damaged composites are found weaker. Numerical modeling on the CAI also supports the experimental conclusion in a great deal. An unsymmetrical load buckling was caused by the corner impact in all the 20 and 30 J tested samples and a prebuckling studies were proposed in the conclusion.

3 Sandwich Composites

Compose of spongy foams or layered honeycombs in core and cladded with the polymeric layers or polymer composite sheets as skin are the sandwich structures. The superior shock absorption capacity of the core material uplift the impact strength of the polymer composite. A similar response is expected in the post-impact characteristic of the sandwich composites and results of the several researchers have support the anticipations.

In their research, author used aluminum honeycomb cells and glass and carbon fiber reinforced composited for face sheet. Different thicknesses of core and face sheets are compared for low velocity impact behavior. Author noted some important observations, as the face thickness increases the impact strength of the composite increased. However, increasing the core thickness did not increase the energy absorption but damage depth is found to be increased (Topkaya and Solmaz 2018).

Low velocity impact study of hybridized carbon/basalt fiber reinforced composite. Neat carbon and basalt composite with 60% volume fraction and 60% wt fraction of carbon and basalt in equal part are prepared. Drop test at different energies is carried out and effect of hybridization on contact force and energy absorbed are investigated. SEM images showed different damage modes as micro cracks, delamination, fiber pull out and fiber breakage. Author reported the improvement in the impact properties with hybridization. However the dominant modes in CFRP and BFRP are fiber breakage and matrix damage respectively (Shishevan and Akbulut 2019).

Low velocity impact tests are performed on carbon fiber reinforced poly-methyl-methacrylate (PMMA) modified with Nano fillers. Ultrasonic NDT is done to find out after impact delamination. Nano-modified composites are observed to absorb 10% more energy than unmodified composite. Author justifies that is because of more interaction of Nano fillers with PMMA (Žukienė et al. 2019).

Carbon fiber reinforced composites (CFRP) with two different resins vynilester and epoxy is investigated in this article for low velocity impact tests. Different impacting energies are used for evaluation of penetration energy and damage propagation. After impact non-destructive tests are carried out to measure the damage. Vynilester based composite shows better results as compared to epoxy based composite (Papa et al. 2019).

Wu and Wan (2019) have developed hybrid sandwich structures using glass fiber reinforced epoxy face sheets and foam core. The face sheets were embedded with and without shape memory (SMA) alloy/conventional 304SS wire nets and the specimens were designed with different orientations and numbers of SMA wires. Vacuum assisted resin infusion technique was followed to prepare the sandwich panels. The sandwich structures were undergone to low velocity impact tests and the results were reported. Digital image correlation technology was used to conduct the After-impact compression tests. The failure mechanisms were analyzed through visual inspections and scanning electron microscopy. The test results revealed that, the sandwich panels embedded with SMA wire were able to absorb more impact energy and possessed better compression after impact characters due to the super elastic behavior of the

SMA wire. More impact energy dissipation was observed in the sandwich panels embedded with SMA wires of cross configuration. The dissipated kinetic energy was transferred to the outer region of the upper face-sheet and the impact resistance of the panels was increased. The failure during the after impact compression test was initiated by the delamination between the face sheet and foam core in the impact region. The propagation of the delamination further reduced the compression carrying capacity of the structure and maximum strain can be identified at the damaged region of the face-sheet.

4 Conclusion

This review article highlighting the importance of evaluating the after-impact compression behavior on engineering materials. Many times, the low velocity impact severely degrades the structural properties of the composites. In particular, the presence of micro damages caused by low velocity impact will seriously reduce the compressive strength of the composite materials. Hence, the impact damage tolerance of primary composite aircraft structures observes more attention in the design of airframe. To evaluate the after-impact compression behaviors, two major issues are need to be considered. First, due to the complexity of the failure mechanism of impact damages, the damage must be simplified on the basis of compressive failure mechanisms of the composites. Second, the failure evaluation of impact damage of composites must be standardized. By these systematic approaches, the after-impact studies are can be conducted to evaluate the compressive load bearing capacity of the materials.

Review concludes that, the research on the CAI and related can be carried by accounting the fiber type, pattern, stacking sequence, aging and filler incorporation. On the other hand, harnessing the modeling tool to assess the compression after impact and other post-impact properties will save the time and materials.

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