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Impact of Fiber Metal Laminates - Literature Research

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The paper refers the general idea of composite materials especially Fiber Metal Laminates (FMLs) with respect to low-velocity impact incidents. This phenomenon was characterized by basic parameters and energy dissipation mechanisms. Further considerations are matched with analytical procedures with reference to linearized spring-mass models, impact characteristics divided into energy correlations (global flexure, delamination, tensile fracture and petaling absorbed energies) and set of motion second order differential equations. Experimental tests were based on analytical solutions for different types of FML - GLARE type plates and were held in accordance to ASTM standards. The structure model reveals plenty of dependences related to strain rate effect, deflection represented by the correlations among plate and intender deformation, separate flexure characteristics for aluminium and composite, contact definition based on intender end-radius shape stress analysis supported by FSDT, von Karman strains as well as CLT. Failure criteria were conformed to layers specifications with respect to von Misses stress-strain criterion for aluminium matched with Tsai-Hill or Puck criterion for unidirectional laminate. At the final stage numerical simulation were made in FEM programs such as ABAQUS and ANSYS. Future prospects were based on the experiments held over 3D-fiberglass (3DFG) FMLs with magnesium alloy layers which covers more favorable mechanical properties than FMLs.

Keywords: failure mechanisms, FML, GLARE, low velocity impact.

1. Introduction

A fibre-reinforced composites are widely used in various branches of industry due to advantageous mechanical properties. Relatively high stiffness of the structure in comparison with low weight described why this kind of materials is under the observation of military as well as aerospace industries. Nowadays, the most significant composites are related to Fibre Metal Laminates which are composed of alternating layers of metal alloys and fibre-reinforced composite [1]. Nevertheless, both composites and hybrid structures are characterized by rather complex behavior.

Implementation of the FMLs into industry requires many experiments and analysis which confirm the proper responsiveness of the material with reference to mechanical properties. One of the most significant effects is a low-velocity impact event which affects structural integrity of composite material by complex failure mechanism relations. There are several parameters taken into account such as: energy dissipation mechanisms [2, 3, 4], static indentation and quasi-static load-deflection curve which are responsible for the response of investigated material under the influence of impact [5, 6]. According to the FML materials [7, 8] especially GLARE (Glass Reinforced Aluminium) there is a huge disparity between composite panel configuration and failure occurrence. The speed of low-velocity impact is assumed to be less than 10 m/s [6, 9]. This event is under the investigation of analytical, experimental and numerical methods. Analytical solutions are related to a basic concept of mechanics with reference to energy absorption mechanism. Nevertheless, experimental procedures reveals the visualization of the problem with respect to held testing research. Obtained results are almost usually compared with numerical simulations made in specialist software such as ABAQUS or ANSYS which are based on Finite Element Method. As it is mentioned before low-velocity impact is rather a complex event in comparison with the current technological possibilities [10, 11, 12].

2. Impact of Fibre Metal Laminates

Over the years aircraft structures were under investigation due to impact damages. Impact can be related to various sources but the most significant are low and high velocity collisions. This occurrences can be caused by maintenance damage, runway litters, hail or bird strikes [13, 14, 15, 16, 17]. In this paper the main considerations were made over low-velocity impact events. Low-velocity impact [6, 9] is handled as a quasi-static deformation process [5, 6] and velocity of the collision do not exceed 10 m/s. Taking into account the mechanical characteristics, composite materials are brittle, however the absorption of the impact energy is noticed just in elastic region against undergoing various modes of failure. FML is the appropriate material which represents the combination of metal benefits and matched with it composite structures developing its impact damage resistance. Impact event is under the influence of transverse non-linear dynamic load as well as the lack of direct thickness reinforcement. Transverse impact damage resistance reached the miserable level for composites [16]. Low strength among the ply, inter-laminar stresses which are mainly shear and tension, triggers delamination attended to matrix crack developing fibre damage. Taking everything into consideration, Fig. 1 represents the aspects of low-velocity impact event. All in all, it is very significant to verify the different failure modes and propagation in view of impact to fully realize benefits of metal content in structure of FML [11, 12].

2.1. *Parameters influencing impact behavior of FMLs*

FMLs behavior under impact event is dependent upon different parameters and analysis related to various loading conditions during pre- and post-impact stages. This parameters are classified into two main groups which are connected with material (types of laminate materials, layup configuration of the structure, composite volume fraction, surface and bonding treatment) and geometry (post stretching, scaling effect, impactor characteristics, pre-stressing) based parameters. Nevertheless, there are some additional criteria matched with overall experimental conditions and energy-dissipation mechanisms. The choice of the type of the analysis is based on impact behavior with its direct relations selected in comparison with geometry, structure and application of tested FMLs [10, 11, 12].

Thus starting from the response of FMLs [18] under impact contingent upon parameters connected with material and geometry characteristics it was proved that the total composition of composite material is significantly responsible for its behavior during impact event. The most common used material for metal layers are some aluminium alloys [19] due to its high ductility [20] and extraordinary mechanical properties. Concerning the GLARE [21] panels another important part of the structure integrity is a matrix and glass fibres orientation. Matrix is usually composed of thermosetting polymers which are characterized by high strength, stiffness and thermal stability [22]. There are also some drawbacks related to requirement of long processing cycles for proper bonding correlations. As it was mentioned before for this kind of material another significant element is glass fibres orientation. Depending on it, the behavior of GLARE under the influence of any kind of failure which may occur, can be predicted by mechanical properties of material, impact tolerance related to damage criteria or strain rate dependences and post-impact responses of FMLs [10]. Taking into account another significant parameters characterize the failure under the influence of impact event is the FML stack orientation and layup configuration. In this type of failure considerations the dependences related to strain to failure ratio occurs due to the type of the laminates fibre orientation. Responsiveness of composite to the impact depends on the individual dimensions of the respective layers [23]. The coefficient responsible for this set of properties is a total thickness. All in all, the thinner aluminium layers represents superior membrane deformation due to higher level of specific energy to fracture. Another significant parameter is metal relative volume fraction in fibre reinforced polymer composite which is accountable for impact response [22]. Pre-stress of composite materials is also matched with impact behavior related to exploitation of structure which is continually under the influence of stresses when impact event is performed. Concerning the division of the parameters related to impact effects the experimental conditions should be also taken into consideration. During the various types of tests which simulates impact events on FMLs there are several types of used impactors and projectiles. Proper estimation of impact resistance depends on geometry and structure of impactor. There are several common types such as soft or hard body, spherical and ballistic impactor. Mentioned various types of impactors significantly affect impact response of FMLs. Different parameters which defines the size and shape of impactor change the influence of impact into structure integrity of the tested component. In a case of small impactors affecting tested specimens there are plenty of damage regions allocated directly in the neighborhood of the site of impact, moreover the larger impactors cause fewer local damages at the impact space. This makes appealing the values of maximum perforation, the impact energy and produced maximum impact force. The general size of composite also plays a crucial role because in a case of size increment the reduction of stiffness occurs which is characterized by load-displacement curve and maximum value of load. This relation rises the dissipation of energy during fracturing processes for plastic and elastic energies. Nevertheless, FMLs geometry also plays a vital role because during the comparison of square and circular cross-sections the serious differences in corner deformations have been observed. Basing on this information impact response of composite is feasible in accordance to force-deflection laws [10, 12].

2.2. *Energy-dissipation mechanisms*

With reference to FML experimental tests there are several observations related to post-stretching [1], delamination [1] and fibre bridging [1, 22] which are the most significant ways of post-impact energy dissipation. During the crack inception or fracturing released energy must be dissipated through different mechanisms due to the sudden failure prevention of a structure. Coming back to post-stretching phenomena the energy caused by the impact is dissipated among stretching of the layers. Residual stresses which are the effect of post-impact behavior are produced alongside of the specimen thickness, influencing on the fatigue capability of the structure. Successive method is delamination as an energy dissipation mechanism connected with laminates impact stresses. Below impact, FMLs undergoes debonding [24] in case of crack initiation which depicts the delamination of reference layers [25]. This method shows the released energy way out on the other side of fracture and suppresses the flow of energy along the laminate by refraining and constipating the fibre failures located in delaminated region. Another energy dissipation method is fibre bridging which is matched with load transfer between metal layers and fibres due to the beginning of metal layer cracking [1, 26]. This phenomenon provides an extraordinary fatigue life of FMLs by reduction of crack growth [22] and bridging the fatigue cracks. This method proceeds the relations with delamination sets taking into account adhesive bonds degradation. Concerning this phenomena connection the balance among delamination and fibre bridging is very significant and projects the influence of adhesive bonds' strength to fatigue and failure [1]. Taking into consideration all the dissipation energy mechanisms, delamination is a phenomenon which connects each other. In composite materials delamination should be taken into investigation mainly at the cases when high-energy impact occurs. Nevertheless, in low-velocity impacts this method can be negligible. In GLARE composites delamination can be observed due to the separation of the layers caused by lower level of mechanical toughness [27]. This phenomenon also is currently visible taking into account cyclic stresses, material imperfections, impacts or compression loads [28]. Fibre/epoxy or metal layers are weak points of the structure which remain under the influence of delamination . This property of energy dissipation must be in balance with other methods or features to obtain the proper working conditions [10, 12].

3. Analytical Modelling of Low Velocity Impact on FMLs

According to the analytical point of view one of the most crucial parts is the general morphology of impact dynamics. This issue is related to impact, impact resistance, impact energy [3, 29, 30, 31, 32] and indentation. Generally, impact resistance is the structure ability to deflect fracture under the influence of applied stress at high speed conditions [10, 11]. Afterwards, impact energy represents the toughness characteristics of materials and correlations between contact of forces in time which causes local cracks in subjected regions. Impact is a contact event among the impactor and tested object. Another significant property is indentation which defines the distance jointing impactors tip and tested surface [32, 33]. Relations connected with contact force and indentations can be defined by Hertz contact law. Solution models are divided into four main categories: spring-mass models, energy balance models, complete models and novelty methods. Successive point describes analytical development in FMLs available models. Taking everything into consideration, analytical modelling of low velocity impact is rather freshman study. There are several limitations recognized in all the stages starting from only elastic region investigation and ending on linearized contact law. Nevertheless, many phenomena are still developed by implementing various boundary conditions and displacement functions [11, 12].

An analytical point of view plays a significant role in final results analysis and such considerations were made by Bikakis [34, 35, 36, 37, 38] who tried to predict the behavior of GLARE circular plates under the influence of low-velocity impact effect. Impact was simulated by the support of impactor with hemispherical tip [26, 39] with constant radius and circular GLARE plate with defined dimensions [34]. Investigated event was performed in the range of applied loads which imitate the loading and unloading effects influencing on tested structure behavior [34]. This problem was solved experimentally by Guocai [35] and upgraded by Hoo Fatt with a spring-mass model developed as a two degrees of freedom model [40]. Considering the experiments described in [41, 42] the plate was impacted by the large mass impactor [41] with defined initial velocity. The tested circular plate was clamped around edges. The progression of the load caused by impactor was related to global deflection with respect to central areas of the plate. Nonetheless, the created spring-mass model was linearized for more detailed low velocity impact effect divided into three main stages [34]. The first one was matched with the initial movement of the impactor which starts the deformation based on delamination occurrence. Second step affected the maximum deformation behavior of the plate. Finally, the last one responded for the impact load characteristics due to the final path and position of impactors movement [34]. Evaluation of this experiment was performed analytically supported by set of motion second order differential equations with impact phenomenon based on kinetic and absorbed impactors' energy [34, 43]. Starting from the analytical part the first calculations were focused on governing differential equations representing the linearized stiffness [44] for both loading and unloading stages [43-45] modelled with reference to linear spring-mass concept and permanent dent depth dependences [44, 46, 47]. Another step was performed by introducing the impact deflection as well as load time history. Considering the impact load in this stage the length of the effect was compared with 1 of free vibrations period for tested spring-mass model [44]. This duration was at the same level for both loading and unloading intervals [34]. Afterwards, such phases were introduced as impact velocity and energy time history. Presented parameters were associated with delamination load as well as energy [40, 44, 48] which was dependent from the kinetic and absorbed energy [48] with reference to proper definition of one of the low-velocity impact stages [34]. All made assumptions were not sufficient for proper results predictions and estimations so the parameter such as restitution coefficient was introduced. This coefficient is responsible for the characterization of the collision effect between impacted objects [49]. This quantity is dependent from the velocity of the event and the single defined parameters of impactor as well as investigated GLARE plate [4]. The quality and efficiency of presented analytical methods performed on circular plates allowed the engineers to expand the testing procedure also for rectangular GLARE plates [35]. The line of thought contributed the comparison of the results at the same planes for two different materials and test configurations. Correlations between final results were published by Guocai [35] and Bikakis analytical model investigation [34]. Taking everything into consideration, the analytical way of thinking fully demonstrates the significant correlations and predictions of GLARE plates with dynamic response properties due to the low-velocity impact events. Nevertheless, this method reveals the wide range of possibilities dedicated to time history characteristics and collision coefficient specifications. Presented model depicts the complete derivation scheme with boundary conditions and basic mechanical assumptions. All in all, such approach is rather time consuming and complicated but shows the whole way of proceeding as well as validation improvement [12, 34].

In contrast the analytical approach of engineers from Delft University of Technology was completely different. Presented by them low-velocity impact experiment was also performed by the contact between hemispherical impactor and rectangular GLARE plate [3]. In this way of thinking first stage of calculations were related to contact definition and specification [3, 50]. Afterwards, the stress and strain dependences were investigated by support of Classical Laminate Theory and FSDT. Further analysis was compared with implemented failure criterion conformed to layers specifications with respect to von Misses stress-strain criterion for aluminium [51, 52] matched with Tsai-Hill criterion for unidirectional laminate. One of the most significant parts dedicated to impact characteristics is determined by total absorbed energy [2, 4] equation which was composed of global flexure [3], delamination [45, 53, 54], tensile fracture [40] and petaling [2, 3] absorbed energies. Nevertheless, the threshold perforation is represented by impact kinetic energy [3, 12].

4. Experimental and Numerical Simulations of Low-Velocity Impact

Simulation of composites dynamics, non-linear and transient behavior under the influence of impact loading is complicated due to contact loading localization and failure mechanisms of integrity of impacted structure. During the impact effect occurrence along the thickness direction mechanical properties become deteriorated [3]. In this state plane stress considerations are no longer significant. Another problematic issue is delamination connected with inter-laminar damage which causes stiffness degradation by changes in stress components through the thickness of the material. This characteristics can be only introduced by 3D models which completes stress and strain fields supported by analytical equations. To fulfil all simulation requirements the modelled structure should be composed of material data presenting stress and strain characteristics, mechanical properties, inter-laminar damage as well as cracking propagation. Nevertheless, coming back to delamination the introduced structure should be composed of layers programmed as solid or shell elements with all loading forces. Taking everything into consideration, modelling of low-velocity impact is rather complex procedure but there are several approaches which simplifies the way of thinking such as failure criteria, fracture mechanisms, damage mechanisms or surface yielding visualization [11, 12].

Researchers from Delft University of Technology presented the experimental method performed on two types of GLARE - called GLARE 5-2/1-0.3 and GLARE 5-2/1-0.4 [3]. Tests were performed on four prepared specimens at room temperature conditions. The main aim of the experiment was the determination and observation of impact threshold in accordance to ASTM D5420 method [55]. Material properties of composite structure tested were described in the following publications [56, 57, 58, 59]. The model structure reveals plenty of dependences related to strain rate effects [60]: deflection profiles represented by the correlations among plate and intender deformation as well as flexure characteristics separately for aluminium [40, 61] and composite [50], contact definition based on intender end-radius shape influencing in radial contact among FML and projectile location [62], stress analysis which takes several assumptions which meliorate the overall quality of analysis supported by FSDT, von Karman strains as well as CLT, failure criteria conformed to layers specifications with respect to von Misses stress-strain criterion for aluminium [51, 52] matched with Tsai-Hill criterion for unidirectional laminate. One of the most significant parts dedicated to impact characteristics is determined by total absorbed energy [2, 4] equation which was composed of global flexure [3], delamination [43, 53, 54], tensile fracture [40] and petaling [2, 3] absorbed energies. Nevertheless, the threshold perforation is represented by impact kinetic energy which is useful for comparison reasons [12].

When it comes to the first part of result analysis the investigated damage on the specimens forced by low velocity impact reveals the aluminium failure modes related to plasticity behavior as well as cracking regions. In case of GLARE panels failure modes [2] ignores the internal failures observed in matrix and fibres due to the comparison with delamination. Predictions made at the beginning stage were successfully confirmed by the test results and show that 81% of impact energy in 2024-T3 aluminium plates was absorbed by deformation which states that this material is an impact resistant structure. Nevertheless, GLARE is more resistant due to the more complex composition matched with connections between absorbed energy and structural efficiency [48]. About presented impact characteristics the behavior of tested materials into low-velocity impact event depicts the dependences with respect to displacement as an evolution of force and energy. Full failure mechanism and sequence with accent into material degradation are presented in [3]. Coming deeper into GLARE layers sequence maximum forces and values of absorbed energy were visible mainly in aluminium failure by managing impact behavior of investigated composite. That feature displays and emphasize the importance of material constituents role [48]. Another significant parameter is membrane stiffness of the component which in point of GLARE, is at the high level. This property reveals the behavior connected with displacement and delamination processes [48]. However, delamination is related to one of the most common failure modes of FMLs during the accelerating experiences showing the aluminium layers failure and the highest stress zones [48]. Generally the main difference in deformation for tested materials is between the scale of this event dividing it into globally for GLARE and locally for aluminium [48]. To sum up, the analysis shows that the rear aluminium layer fractures at the end. This process must be predated by failure of all remaining layers at impact region [2, 56]. Investigated materials validate the role of material constituents in the whole structure basing on elementary principles such as CLT and FSDT. Taking everything into consideration, impact parameters prearranged at the beginning of the experiment became confirmed and were placed in the assumed level of confidence. Aluminium and GLARE are named as impact resistant materials which is advocated by at least 81% of energy absorption across plate deformation under the influence of impact event. What is observed additional that GLARE owns the unique feature related to the level of energy threshold. This material can resist serious deformations basing on high membrane stiffness characteristics. This experiment fully illustrates the division of the roles of respective materials which forms FMLs with further evaluations and combinations of properties proportionality and quality development [12, 48].

Within the final part of that analysis the behavior of aluminium material model verification was performed at relatively high strain rates and it is arranged with the reference concerning quasi-static damage model [14]. Another assumptions are matched with ultimate strength which does not affect directly into strain rate due to intensity of flow stress with respect to impact strain rate as well as ductility characteristics [40]. The positioning of the layers plays a significant role in case of deformation. Rear layer of aluminium stands for larger deformation in contrast with front panels basing on underneath layers prevention properties [3]. Impact resistance depends strictly on fibre orientation with correlations to plate geometry and rising metal volume fraction. Failures in tested model were performed by implementation of von Misses and Tsai-Hill criteria. This takes into consideration the whole structure of the composite as well as separate layers characteristics and introduces the general rule that failure layer stops carrying the load in surroundings of impact location and then stiffness of failure layer was equal to zero. Nonetheless, this statements did not affect significantly in this type of experiment [3]. In the discussion of the results there were several effects taken into account as: effect of projectile mass [3, 23], laminate variables [2, 32], theoretical effect of residual curing stresses [3, 63], effect of plate size [3] and energy dissipation [3, 29, 32]. One of the most important part of the results discussion was damage scenario related to damage modes initiation with absorbed impact energy [64] as well as correlations among force-displacement curve and initiation of failure modes [65]. From the theoretical point of view the investigation developed on tested GLARE can be reconstructed by presenting damage sequence matched with impact energy level changes. However, the experimental procedure depicts that impact responsiveness does not affect directly from values of maximum forces and specific failure modes. All in all, when the crack became initiated especially in aluminium layer the opposite side of the composite reaches the growth in inter-laminar delamination [3]. When it comes to impact response of tested GLARE 5-2/1-0.4, aluminium laminas dissipate around 90% of overall absorbed energy. This correlations are presented basing on aluminium layers behavior. The composite core deferments initial cracks due to the flexural deformation modifications of the aluminium profile. Simultaneously, the behavior of front and rear aluminium layers illustrates the impact region with delamination and dampens processes. Taking everything into consideration, GLARE represents sophisticated impact-prone structure basing on failure mechanisms efficiency [3, 12].

In contrary scientists from Lublin University of Technology decided to compare the results of experimental and numerical results of low-velocity impact event. Prepared testing material was composed of aluminium 2024-T3 and GFR composite layers. Low-velocity impact was simulated by the support of Instron Dynatup 9340 testing machine according to ASTM D7136 standards [66]. Used impactor had hemispherical tip with defined diameter and mass [67]. Investigated effect was performed in the range of velocities from 3.16 m/s up to 4.98 m/s with energy distribution dependent from the drop height [67]. Numerical model was performed in accordance with ASTM D7136 standards. Initial parameters describing impactor characteristics were the same as in case of experimental procedure but the impact velocities were strictly assigned to corresponding impact energies: 3.16 m/s – 10 J as well as 4.98 m/s – 25 J [67]. The overall behavior of the system was described by the introduction of failure criteria: Hashins' tensile criterion [51], maximum stress failure criterion [68], matrix failure in tension and compression [69, 70], damage failure or degradation mechanisms. All in all, the detailed information connected with model features, boundary conditions and reliance between structures was described in [12, 67]. The following study fully describes the experimental and numerical investigation of low-velocity impact resistance of FMLs. This event was tested in various conditions dependent of impact velocity and energy. The obtained solutions - both experimental and numerical approach, show high conformity associated with force vs. time characteristics. Surprisingly, the final evaluation of the scope of FML damage behavior was at the same level of confidence in experimental and numerical analysis. It was confirmed that impact energy growth was matched with increasing surface damage regions in FMLs individually, independently form the testing method. Generally, damage in tested materials were investigated under the influence of changes in cross-sections which exposed the principal forms of this effect such as delamination or matrix cracks. Thickness increment significantly changes the degree of degradation which was taken into account with delamination and deformation processes. Due to the variety of similarities between testing methods numerical simulations fully revealed the damage scenario in cross-sectional areas. Thus, both experimental and numerical methods have benefits and drawbacks but FEA analysis [71, 72] better admits the final results adaptation in future prospects [12, 67].

Another significant scientific research over low-velocity impact were performed in Nanyang Technical University comparing experimental [60] and numerical simulations. Presented approach was made on circular samples which are a little bit different than standard testing specimens for composites, additionally it depicts the comparison of unidirectional and woven FMLs [17]. Low-velocity impact was simulated by the application of Instron Dynatup 8250 testing machine and Instron 5500R for quasi-static indentation simulations. Specimens used for investigated effect was divided into three categories concerning different velocity range equal to 2 m/s up to 3.1 m/s with energy distribution dependent from the drop height and test types as well as used impactor [32, 33]. The overall behavior of the system was described by the introduction of Johnson-Cook mechanical models concerning stress rate effect and damage criteria [12, 51].

In woven structures the growth of impact energy [31] distinguished the characteristic region with the direct impact area showing the fracture and penetration occurrence zones. Generally, presented deformation profiles are approximately symmetrical with reference to panel center in both directions [73]. Nevertheless, in case of unidirectional composite deformation effect was performed at the same conditions but with the ignorance of panels perforation which revealed that profiles were not symmetrical taking into account fibers direction [73]. FEA simulations depicted the initial stages of damage progression which causes cracks due to the increment of impact energy [30]. This method revealed the impacted area under the influence of still rapidly changing conditions. The final impact investigation with reference to marked damage sections acknowledged the claimed prediction and scenario [73]. Tested FMLs supplied the information concerning damage scenario related to initialization contact area with crack propagation towards the weaker points of aluminium parts of the composite. Aluminium layers revealed the plastic areas which initiates the boundary conditions related to contact forces growth influence. Nonetheless, claimed phenomena depicted the significant domination of plastic deformation in comparison with deflection of tested composite specimens. Correlating finally the used types of FMLs basing on fibres configuration, unidirectional fibres represented better impact resistance properties than woven ones. What is more, the additional difference concerned the deformation profiles in case of woven fibres are symmetrical taking into account panel center in both directions but in unidirectional fibers profiles were not symmetrical with reference to fibers orientation [12, 73].

5. Future Prospects of Low-Velocity Impact Event

For years many low-velocity impact simulations were performed on FMLs. Mainly GLARE [23, 32, 48] was the most valuable composite structure but on the horizon together with testing methods evolution the new set of materials appeared. One of the best well known are 3D-fiberglass (3DFG) FMLs with magnesium alloys layers [69]. 3DFG is a revolution in composite materials which significantly increases the potential of applications such as automotive and aerospace industries. The structure of this laminate is composed of bi-directional woven fabrics minted with plaited glass fibres pillars [74]. This unique and innovative manufacturing technology allows the better mechanical properties than FMLs used up till now. Coming back to the structure of the composite layers they are mainly made of mixture of aluminium and specifically tailored composites but in case of the innovative side the aluminium is replaced by magnesium alloys [69]. This modification significantly lowers the density and upgrade strength to weight ratio [23, 75] in comparison with GLARE. Mentioned parameters lead in automotive industry where the costs reduction and innovations deal with customers preferences. Despite of many benefits FMLs with magnesium alloy layers are not so well known and there are a limited number of performed experiments [76] as well as analysis associated with low-velocity impact events [22, 24, 77, 78]. Dalhousie University researchers performed the experimental procedure for testing 3DFG in accordance to ASTM-C393 standards which was compared with ABAQUS numerical simulation. The model of bi-directional woven structure was programmed by support of VUMAT patch which defines the damage initiation evolution mechanisms [32, 59, 69]. Nevertheless, damage behavior was supplemented by failure criterions such as Hashins'[51] and Pucks'[70] both for matrix as well as fibres. In case of this type of the material an additional ductile damage criterion was implemented. All in all, the investigated damage impact predictions were performed basing on fracture energy in taking into account ASTM standards. Taking everything into consideration 3DFG are characterized by more optimal mechanical and engineering properties than GLARE composites. Conducted simulations revealed the upgrade of such properties as stiffness as well as energy absorption [69]. However, with reference to various technology branches maintenance bi-directional woven sandwich structures presents lower material costs and weight in contrary with commercially used FMLs. To sum up, the final results of held experiments and numerical simulations displayed the benefits of invented sandwich structures but when it comes to the validation and implementation stages, advantages transforms into complicated problems or time consuming considerations [12, 69].

6. Conclusions

Low-velocity impact event is one of the most significant part of the overall composite specification. Generally this effect is rather characterized by complex behavior. This work reveals the experimental, analytical and numerical investigations over this kind of problem taking into account different specimens specifications, various testing sequences as well as failure or damage mechanisms. As it was described the accurate analysis is time consuming and tough to follow. Taking everything into consideration, FMLs as a materials are widely used in many branches of industry related to restricted norms. Due to the favorable mechanical properties the tests correlated with further implementation must be performed with respect to accurate precision and validation procedures. Generally, low-velocity impact in case of its complexity allows the researchers to predict the behavior of the composites into goalmouth situations. Described way of thinking depicts the undeveloped potential of material upgrade specifications. All in all, the world of science is still developing new additives to current theories and concepts. Another significant method is numerical ones which is almost continuous upgraded by new information patches. In this work there was mentioned about future prospects related to changes in laminate structure. This modern approach is rather problematic issue due to the necessity of several experimental tests performance. To sum up, low-velocity impact is described as relatively new attempt of composite behavior characterization which will be still under the investigation in the future due to its meaning especially for safe work of many aircraft structure [12].

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