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Effect the stacking sequences of composite laminates under low velocity impact on failure modes by using carbon fiber reinforced polymer

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ABSTRACT

Main problem is naturally raised is how to improve the efficiency and uses of composite materials in the aircraft structures and the aerospace industries. This paper deals with the studying of the effect of stacking sequences for the composite laminate on the failure modes under low velocity impact. Using the carbon fiber reinforced polymer (CFRP) in different layups as three groups (A, B, C). It has same material system but with different stacking sequences to investigate the effect that on failure modes and the composite material resistant to the impact. As well as understanding of the deformation mechanism and the damage that occurs in the laminates under low velocity impact. Through the results of experimental methods were the effect of stacking sequence on failure modes is very clear.

Keywords *- stacking sequences, delamination area, depth of indentation, composite laminates.*

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I. INTRODUCTION

Composite materials are very important in manufacturing processes and uses widely in several areas [1]. The most important of these uses are aerospace industries and airframes to thanks to its strength and stiffness to weight. It has a good resistance to the corrosion and the fatigue. It has been many research on composite materials under low velocity impact through many years. Some studies on the behavior of composite material structure because of its superior characteristics such as high strength and light weight. Textile composite materials are ideal for designers as uses in important parts such as airframes, armor and aerospace industry and cars etc. [2].

Low velocity impact on the composite materials may not produce visible indications on the surface however may intent giant inner damage, for this reason it's doubtless that non-visible harm could arise in the early in the structures and go undetected in the course of service inspections.

This conservative approach is mainly related to the determination of allowable strongly underestimated because of concerns about the impact of low velocity impact damage (LVI) on the performance of composite laminates.

These damages can be classified two parts [3]:

* The intralaminar damages, i.e. the damages establishing inside the ply like matrix cracking, fiber/matrix deboning or fibers breakages.

* The interlaminar damages, i.e. the damages constructing on the interface between two consecutive plies, specifically delamination.

II. Definition of composite materials

Composite materials can be defined as a combination of two or more materials to produce new material with excellent properties. The composite material is formed by fibers that are a source of strength and stiffness while matrix composite source of rigidity and resistance to environmental, as shown in figure (1)

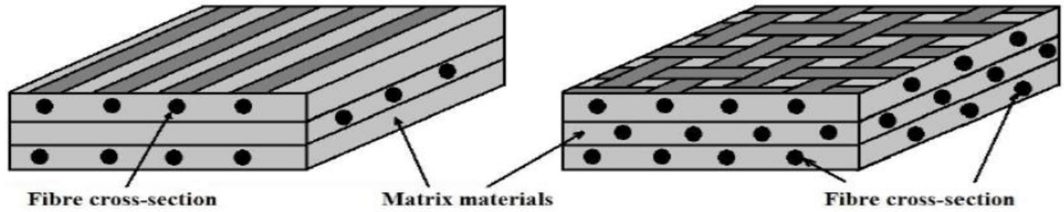


Figure (1) illustration the formation composite materials by using fiber and matrix [1].

The most common advanced composites are fiber reinforced polymeric composites. Polymer matrix reinforced with fibers that are thin diameter high performance are components of the composite. One of the most important reasons that make this the most common composite materials includes high strength, low-cost, simplified manufacturing principles. While the drawbacks of FRPC are low operating temperature, high coefficient of thermal and moisture expansion, and low elastic properties in transverse direction. Fibers occupy the largest volume fraction in a FRPC and share the major portion of the load acting on a composite structure. The reinforcing fibers can be oriented during fabrication; thus composites can be tailored to meet increased load demands in specific directions. The major fibers in use today are glass, carbon (graphite), and aramid. Their mechanical properties are given in the above table [4].

Composite materials may classify according to geometry of the reinforcing phase and the types of matrices [5] as shown in the table (1).

Table (1) classification of composites

Composite materials	
Based on geometry of the reinforcing phase	**Based on the types of matrices**
Particulate reinforced composites (PRC)	Polymer matrix composites (PMC)
Flake reinforced composite	Metal matrix composites (MMC)
Fiber reinforced composites (FRC)	Ceramic matrix composites (CMC)
	Carbon fiber/carbonaceous matrix composites (CCC)
	FRPC (fiber-reinforced polymeric composite), PMMC (particulate-reinforced metal matrix composite)

Composite materials (CFRP) proportion in the aircraft structures is about 52% and, in particular, the wings, and the fuselage as in Airbus A350 aircraft as shown figure (2 and 3).

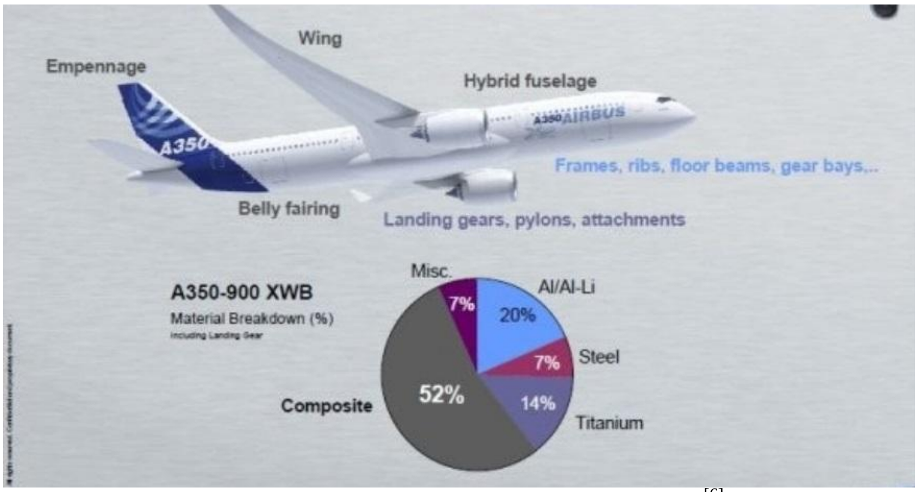


Figure (2) Airbus A350 Distribution of material [6].

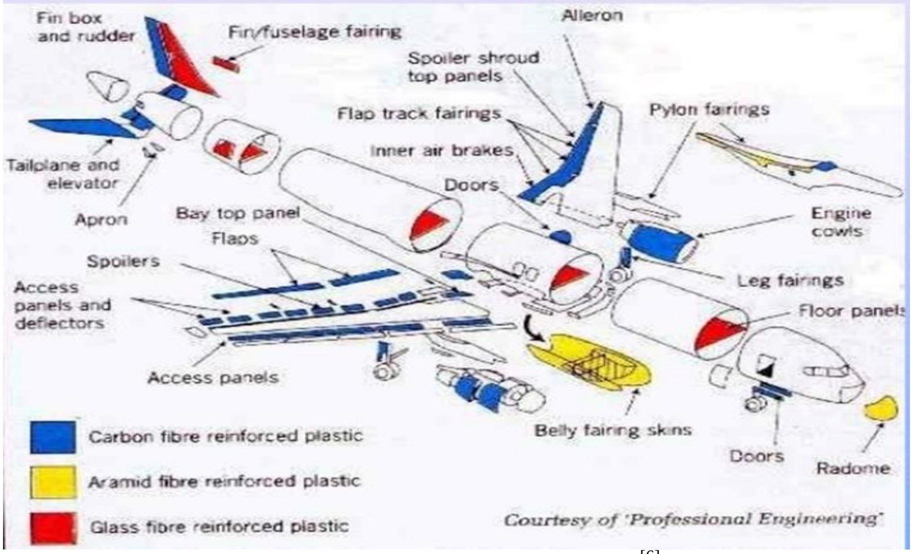


Figure (3) Distribution of composite [6].

III. Definition of low velocity impact

The events which occur within 1-10 m/s depending on the stiffness of target can be called low velocity impact. In the beginning there was discussion by leading researchers on the definition of low-velocity impact due to the uncertain transition between the impact of low-speed and high-speed impact. On the one hand, one researcher has suggested that the generally accepted, Cantwell and Morten [7] that velocity is the effect up to 10m/s. Abrate [8] has been reported that the velocity effects occurred with impact should be less than 100m/s. While Sjoblom et al. [9] and Shivakumar et al. [10] have been insisted that the low velocity impact is varies from 1 to 10 m/s depending on the characteristics of the target materials and the rigidity of the impactor. Very locally damage and waste of energy are due to the impact of high-speed due to the lack of response time and limited the influence of boundary conditions. On the opposite, the low velocity impact will be caused the response of an entire structural and more energy may absorbed in sequences, as due to the impact duration is enough. Davies and Robinson [11] defined the low velocity impact is not simply by both numerical and physical property, and hardly cause effect oriented the pressure of the stress distribution through the thickness. A zone of cylindrical under the impactor is considering to a uniform strain of undergo, as the propagation of stress wave through the plate , so the compressive strain of ultimate gives as ε_c[11]:

$$\varepsilon_c = \frac{transition\ impact\ velocity}{speed\ of\ sound\ in\ the\ material} \qquad (1)$$

Finally, consider the largest impact velocity less than 10 m / s studied in this project, and it has studied belong to the group of low velocity impact.

IV. Failure Modes Of Composite Laminates Subject To Low-Velocity Impact

The failure is a very complicated process, involving two parts ,First The intralaminar damages, i.e. the damages establishing inside the ply like matrix cracking, fiber/matrix deboning or fibers breakages. Second the interlaminar damages, i.e. the damages constructing on the interface between two consecutive plies, specifically delamination and penetration.

Figure (4) illustrated the failure modes as matrix crack, delamination, and fiber fracture. Cracking of matrix occurs parallel to direction of fiber due to tensile, compressive and shear stress. Fiber fracture normally occurs after matrix cracking, Subjected to higher load. The process of separation between the layers with different fiber directions called delamination.

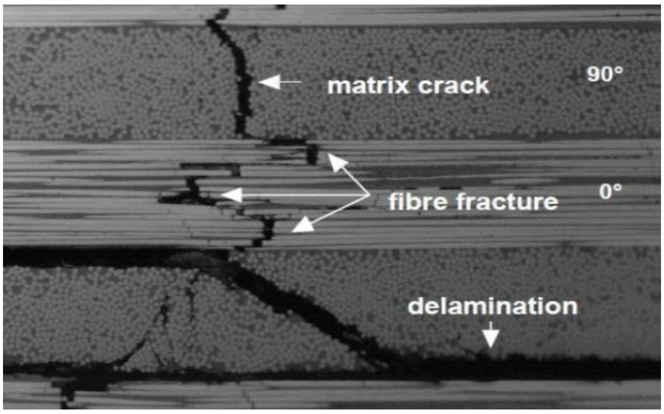


Figure (4) Cross-section view of the impact damaged composite laminates [12].

4.1 Matrix cracking

As a result of tension, compression and shear due to low velocity impact occurs the phenomenon of matrix cracking that is parallel to the fiber. Matrix cracking is the first type of failure. Influence of matrix cracking on structure of composite materials, it is reducing the strength properties of composite.

4.2 Delamination

The process of separation between the layers with different fiber directions called delamination. Delamination damage is the most critical damage in the composite materials under low velocity impact. it plays a key role and dominant position in energy dissipation and damage composite laminates under low-velocity impact and interact with matrix cracking and contribution reached to 60% degradation in compressive strength in the laminates[8,14]. Figure (5) shows the interface between layers of delamination damage mechanism with different directions of fiber based on experimental studies [14-17].

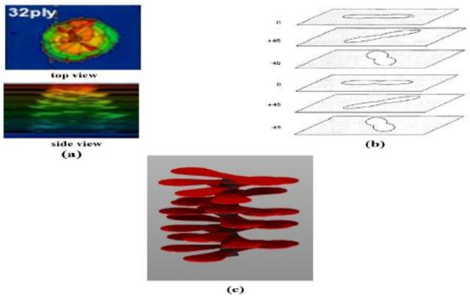


Figure (5): (a) Top and side views of the delamination area from C-scan observations [12]; (b) schematic illustration of delamination [8]; (c) ideal model of delamination [12].

4.3 failure of fiber

Matrix cracking is a prelude to delamination and that it leads to a reduction in strength of composite laminates under low velocity impact. And then it leads to a significant failure in composite laminates, is break the fiber under impact of relatively high energy as a result of loss of protection provided by the damaged Matrix of which do so to a high concentration of stresses around the fibers causing the failure and break those fibers. There are two types of fiber failure: first, the fiber breaking of tensile and second, the fiber buckling of compressive.
Figure (6) illustration the mechanism of failure modes of composite materials under low velocity impact.

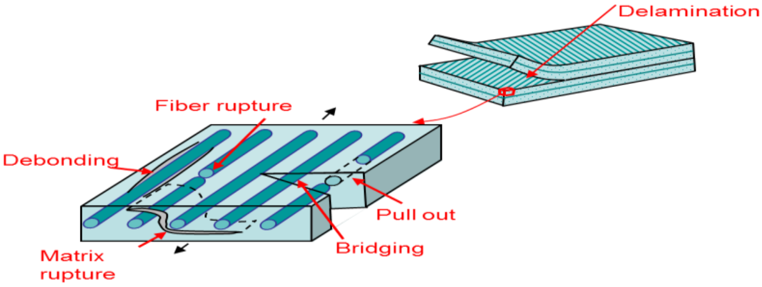


Figure (6) the mechanism of failure modes of composite materials under low velocity impact [13].

- **Depth of indentation**

Indentation is defined as a difference between two points, the lowest point in the Dent and surface. in the aerospace industries , the damage tolerance corresponding to impact loads, leads to body dimensions according to the susceptibility effect: If the damage is not clear, which can detect when the Indent depth effect is less than a certain value, named barely visible impact damage (BVID), the structure should support extreme loads, if the damage is detectable, when indentation depth effect is greater than BVID, it must be considered as another criterion, such as the repair or replacement of the chassis [18,19].
BVID defines minimum damage which can be discovered by Visual evaluation [18]. The field of aerospace, it has proven to be a depth indent between 0.25 and 0.5 mm can be detected during the detailed visual inspection with a prospect of largest than 99% [20].

V. An Experimental Tests

5.1 Manufacturing of specimens
The specimens were manufactured in one of the factor of composite materials in the People's Republic of China according to specification ASTM UD carbon/fiber--epoxy/D6641 (EM114-30%-A12-U-150gsm-1000) based on 0^0,45^0,$-45^0$and 90^0 as shown in the table (2) and the design of stacking sequence as shown in table (3).

Table (2) Mechanical properties of UD ply

Property, unit	value
Young's modulus (0^0), Gpa	133.58
Young's modulus (90^0), Gpa	9.25
Tensile strength(0^0), Mpa	1368.19
Tensile strength(90^0), Mpa	178.42
Density, g/cm^3	1.78±0.02
Elongation,%	1.6~2.1
Carbon content,%	91~94
Poisson's ratio	0.3±0.012

Table (3) design of stacking sequence for composite materials

Layup name	Stacking sequences	Plies	Dimensions mm	Thickness mm(average)
A	$[90_2,-45_2,0_2,45_2]_{2s}$	32	150*100	4.2575
B	$[0_2, 45_2,-45_2,90_2]_{2s}$			4.32
C	$[45_2,0_2,90_2,-45_2]_{2s}$			4.48

5.2 Impact test system (low velocity impact)
The test system of low velocity impact was using the machine as shown in figure (7) which was in the state key laboratory of mechanics and control of mechanical structures of Nanjing University of aeronautics and astronautics. All the details of the tests are in the table (4)

Figure (7) Impact test system of drop weight.

Table (4) the details of impact test system

Impact energy (J)	Impactor mass(kg)	Impactor velocity(ms^{-1})	Drop height (mm)	Diameter of impactor(mm)	Notes
15	5.5	2.3355	278	16	For every composite
25		3.01511	463.34		
35		3.5675	648.688		

The specimens were prepared subject to low velocity impact. Total number of specimens is eighteen. Each two specimens were to one of the impact energy to get accurate results as shown in figure (8)

Figure (8) all the specimens of carbon/fiber-epoxy

VI. Results and discussion

It has conducted tests by impact energy 15 J, 25 J and 35 J for three cases studied. To clarify and verify the effect of stacking sequence for composite laminates on failure modes as following:

6.1 Delamination

As in figure (9) been using ultrasonic c-scan to clarify damage to areas of delamination that expected. Thanks to double-layer stacking configuration, this can be explained by different colours as shown in the figure (10), indicating damage to the composite laminates under low velocity impact. Through this observed there is a clear effect of stacking sequence for composite laminates where the composite B is the most damage from the A and C in terms of shape and delamination area that is described in Fig. (11).

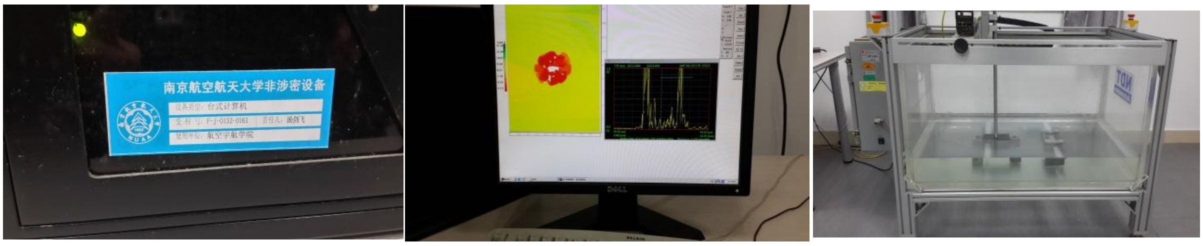
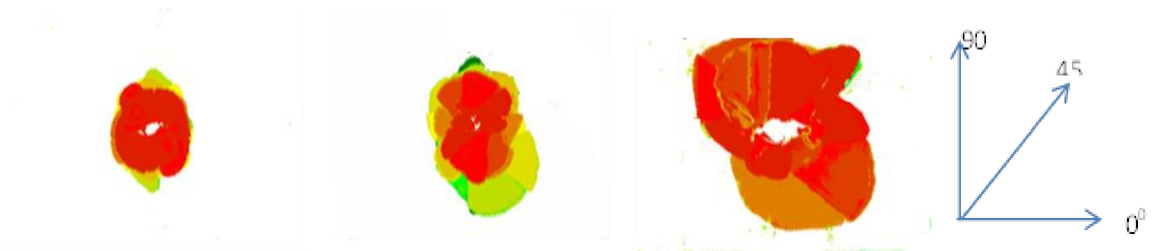
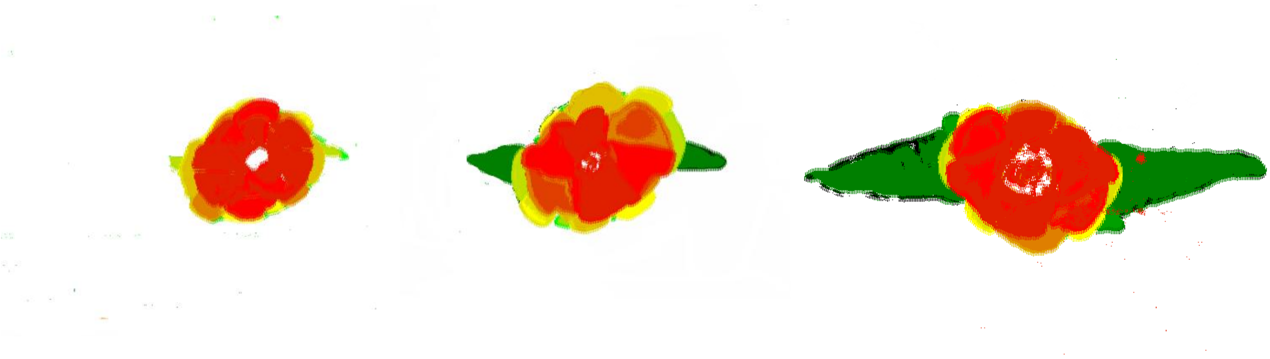


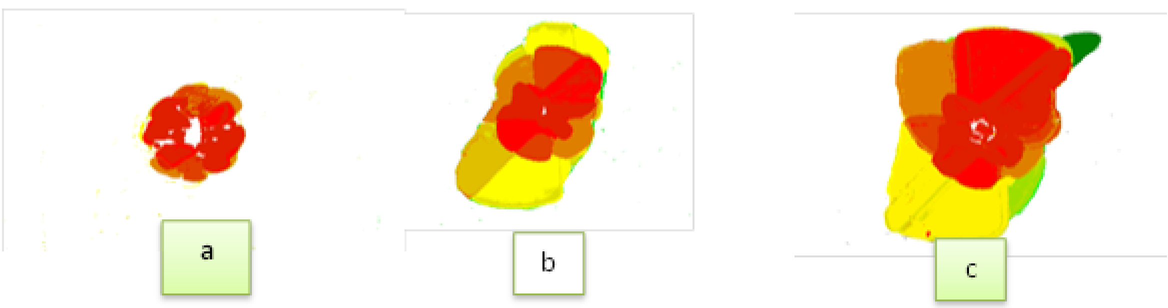
Figure (9) c-scan ultrasonic



A $[90_2,-45_2,0_2,45_2]_{2s}$



B $[0_2, 45_2,-45_2,90_2]_{2s}$



C$[45_2,0_2,90_2,-45_2]_{2s}$

Figure (10) delamination area (a) impact energy 15J (b) impact energy 25 J (c) impact energy 35 J

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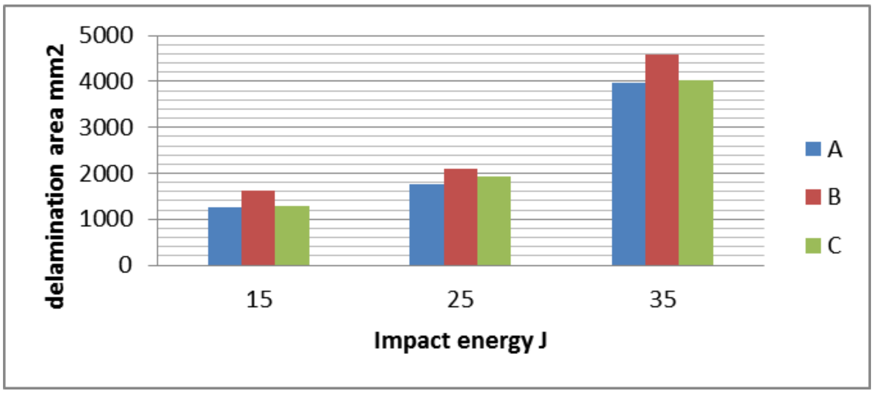
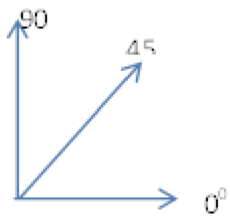
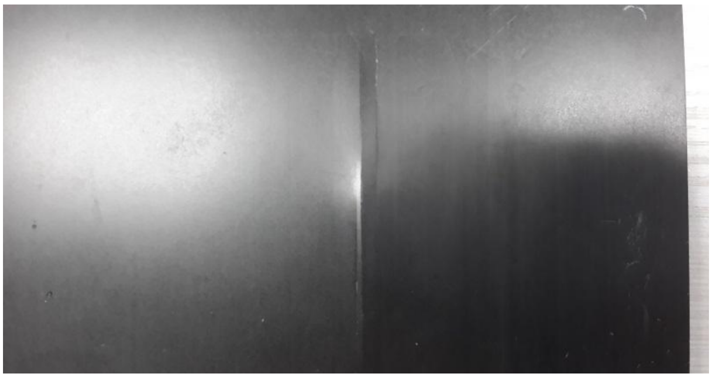


Figure (11) delamination area

6.2 fiber failure

the failure of fiber do not appear clearly in the cases of impact energy 15J and 25J , but when it increased the impact energy 35 J appeared swollen or elevated in the layers reached to the boundary of specimen in non-impact side which as shown in figure (12). The cracking is progressed in a longitudinal reached to the edges and it is a parallel to the fiber direction. Some damage of fiber failure was clear and significant especially in composite B which was most effect. The fiber failure is hard to be visible because their location inside the laminates. it is not like the delamination , can used c-scan to show the damages.





A$[90_2,-45_2,0_2,45_2]_{2s}$

B $[0_2, 45_2,-45_2,90_2]_{2s}$

C[45_2,0_2,90_2,-45_2]$_{2s}$

Figure (12) non-impact side for composites at 35 J

- **Depth of indentation**

Through figure (13) can be observed that the effect of stacking sequence on the Indent depth is clearly so that composite material B is more deeply damage than others (A and C). The relation between the impact energy and indent depth is nonlinear. As mentioned above, the depth of indentation is an important criterion for choice the structure design.

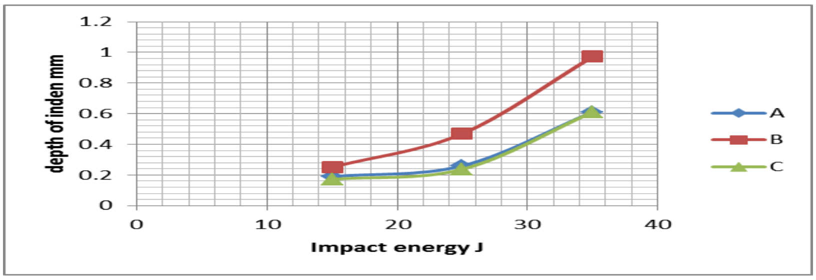


Figure (13) depth of indentation

VII. Conclusion

in this paper was studied the effect of stacking sequence of composite laminates subject to low velocity impact on failure modes by using carbon /fiber epoxy . Through the results of experimental methods was concluded there was a significant effect of stacking sequence on failure modes as following:

a- the damage of delamination was a significant damage for composite B [02, 452,-452,902]2s which was the most damage than A [902,-452,02,452]2s and C [452,02,902,-452]2s.

b- The failure of fiber led crack in the layers of non-impact side reached to the (right and left) edges in the axis 0 for composite B [02, 452,-452,902]2s which it was most damage than A [902,-452,02,452]2s & C [452,02,902,-452]2s.

c- depth of indentation of composite B [0_2, 45_2,-45_2,90_2]$_{2s}$ was the most deeply than A [90_2,-45_2,0_2,45_2]$_{2s}$ & C[45_2,0_2,90_2,-45_2]$_{2s.}$.

Thus, the experimental methods were proved there a significant effect of stacking sequence on failure modes. It is necessary to choice the perfect structure design for aerospace industries especially aircraft structures. In next paper will be build the model to confirm the results by using ABAQUS 6.9.1 and the comparison will be between the experiment results and simulation results.

VIII. Acknowledgments

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