THE INFLUENCE OF PRE-STRESS AND CURVATURE ON IMPACT RESPONSE OF CURVED COMPOSITE LAMINATES

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Abstract
In this paper the effect of pre-stress on impact response of composite laminates is considered. For this aim three various specimens were provided and impacted under 4 different impact energies: 1- A curved laminates without pre-stress (the initial curvature of A). 2- A pre-stressed curved laminate in which the initial curvature of A was changed to curvature of B by pre-stress. 3- A curved laminate without pre-stress and the initial curvature of B. In this way the effect of pre-stress and curvature were considered. The results showed that by applying pre-stress which leads to increasing the curvature (second group) the maximum force and damaged area increased significantly. Comparing the impact response of second and third specimens showed that in the same curvature the pre-stress caused less damaged area which is very important result for designing the structures containing curved laminate.

1. Introduction

A major weakness of laminated composites is that low-velocity impact, introduced accidentally during manufacture, operation or maintenance of the aircraft, may result in delaminations between the plies. Most of the available literature deals with impact on structures without any pre-stresses [1-2]. Usually, in addition to impact loading, composite structures may experience pre-stresses produced either by service loads or by the manufacturing/assembly process [3–4]. Delamination plays a minor role on the residual strength of impacted composite structures subjected to tensile load. Instead, in damaged structures subjected to compressive loading, delamination is most detrimental damage mechanism affecting the structural damage resistance [5,6]. On the other hand, most of the studies regarding the effect of low velocity impact damage reported in the literature have focused on thicker flat plates that are typical of those used for wing structures, but there are a few studies that address the low velocity impact response of thinner curved composite panels that are typical of fuselage skins [7,8]. Although there is some information about these two topics (curvature and pre-stress effects) in the literature, separately, but there is only one study about their effects when both of them attend simultaneously during low-velocity impact loading [5]. In this study, Saghafi et. al used two different specimens to consider the effect of pre-stress on the impact response of curved laminates: 1- A specimen with initial curvature radius of 190mm and without preloading. 2- A preloaded specimen that the initial radius of curvature was 190mm and after applying the load decreased to 125mm. Their results showed that increasing the curvature and the stress through the thickness affected significantly the

impact parameters such as maximum load and damaged area. The shortage of this study is that the contribution rate of curvature and pre-stress is not clear. Because both of them were changed during the pre-loading. So finding the effect of these factors, separately, is very interesting for designers.
In the following study a new test setup is design for understanding the contribution rate of the curvature and pre-stress. For considering more details all impact parameters, i.e. maximum load, maximum displacement, time-duration of impact, and damaged area, are presented. The damaged area are also shown by taking picture from back surface of the damaged specimens for investigating the damage modes in different situations.

2. Experimental program

2.1. Materials and specimen manufacturing

Unidirectional glass/epoxy prepreg (Ref. 1017) supplied by G.Angeloni Srl was used in this research; its mechanical properties are presented in [9]. For finding the effect of pre-stress and curvature on impact response of preloaded curved laminate three different specimens were manufactured: 1- Nine curved specimens without preloading during the impact test (Type A). 2- Nine specimens which their curvature is the same with the last group, but are under pre loading during the impact test (preloaded Type A). 3- Nine specimens that their curvature is the same with the second group (after their preloading) and no preloading will be conducted during impact test (Type B). It should be mentioned that the curvature of the Type A specimens is about 190mm and the curvature of the two others is about 125mm. Since the curvature of the second and third groups is the same, so the effect of pre-stress on impact parameters can be determined. Figure 1 shows the configuration of all samples. The stacking sequence of the laminates is $[0/90/0/90/0]_S$ (10 layers), and width and thickness of the specimens are 100mm and 3.3mm, respectively. Test panels were cured by using a vacuum bag in autoclave at 150^{o}C for 1 h, according to supplier's specifications. Specimens were cut from the laminates using a rotating diamond disk.

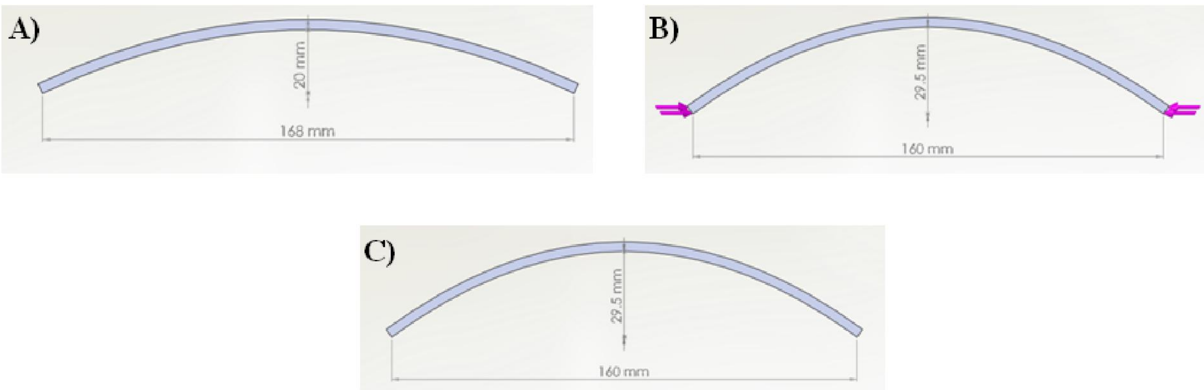

Figure 1. The configuration of all samples provided for considering the effect of curvature and pre-stress: A) Type A B) Preloaded Type A C) Type B.

2.2. Test Setup

Four different drop heights of 0.5, 1, 2, and 3m corresponding to a nominal potential energy of 6, 12, 24, and 36J, and pre-strain of 5300με for group 2 (pre-loaded Type A) were chosen to consider the effect of pre-stressing in different impact energies. For each configuration at least 2 samples were tested. If the results of the first two tests were not near to each other the third test conducted.

The tests were conducted in a custom built drop-weight machine equipped with a piezoelectric load cell attached to the impactor. The signals of the load cell was acquired at 100 kHz sampling frequency without any filtering except the intrinsic one due to the measurement chain. The hemispherical head of the load cell had a diameter of 12.7 mm and the total mass of the impactor was 1.26 kg. The curved laminates were positioned under this drop tower and preloaded by means of a special fixture designed and fabricated to meet the goals of this research [9]. Figure 2 compares the specimens of second (preloaded Type A) and third groups (Type B). As seen, the configuration is exactly the same with this difference that the Type B has tension stress on the front side (impacted side) and compression stress on the back surface of the sample, while preloaded-Type-A sample is free of any kinds of stress. Therefore, by comparing the results of these two groups the effect of pre-stress can be found. All information about the fixture and the method of applying the load is mentioned in [9]. It should be mentioned that there is no fixture on the curved sides of the sample and they are free in all directions.

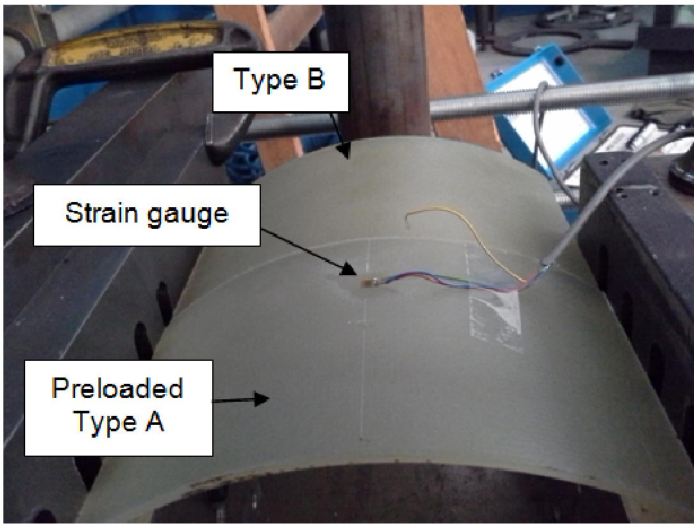

Figure 2. Comparing the specimens in groups of 2 (preloaded Type A) and 3 (Type B)

3. Results and discussion

The Force-Displacement curves obtained from impact tests are shown in Figure 3. As seen the group of "Type B" and "Preloaded Type A" have a very similar behavior, while the group of "Type A" follows a completely a different trend. Since in the "Type A" specimens the curvature is less and also there is no preloading the stiffness is less, but the other two groups the stiffness is almost the same which shows the stiffness is more depends on curvature, not pre-stress. For considering more details, the impact parameters: maximum load, maximum displacement, time-duration of impact, and damaged area are presented in Figures 4 and 5.
According to Figure 4 all impact parameters are very similar to each other for the "Preloaded Type A" and "Type B" specimens that shows pre-stress does not affect significantly on these parameters. On the other hand in the "Type A" specimen in which the curvature is less and there is no pre-stress, the impact parameter is completely different. Therefore, the maximum displacement and time-duration of impact is more and maximum force is less in comparison with two other configurations. It is related to this fact that when the curvature is less, the

stiffness decreased and so under the impact loading less force can be transferred to the specimen.

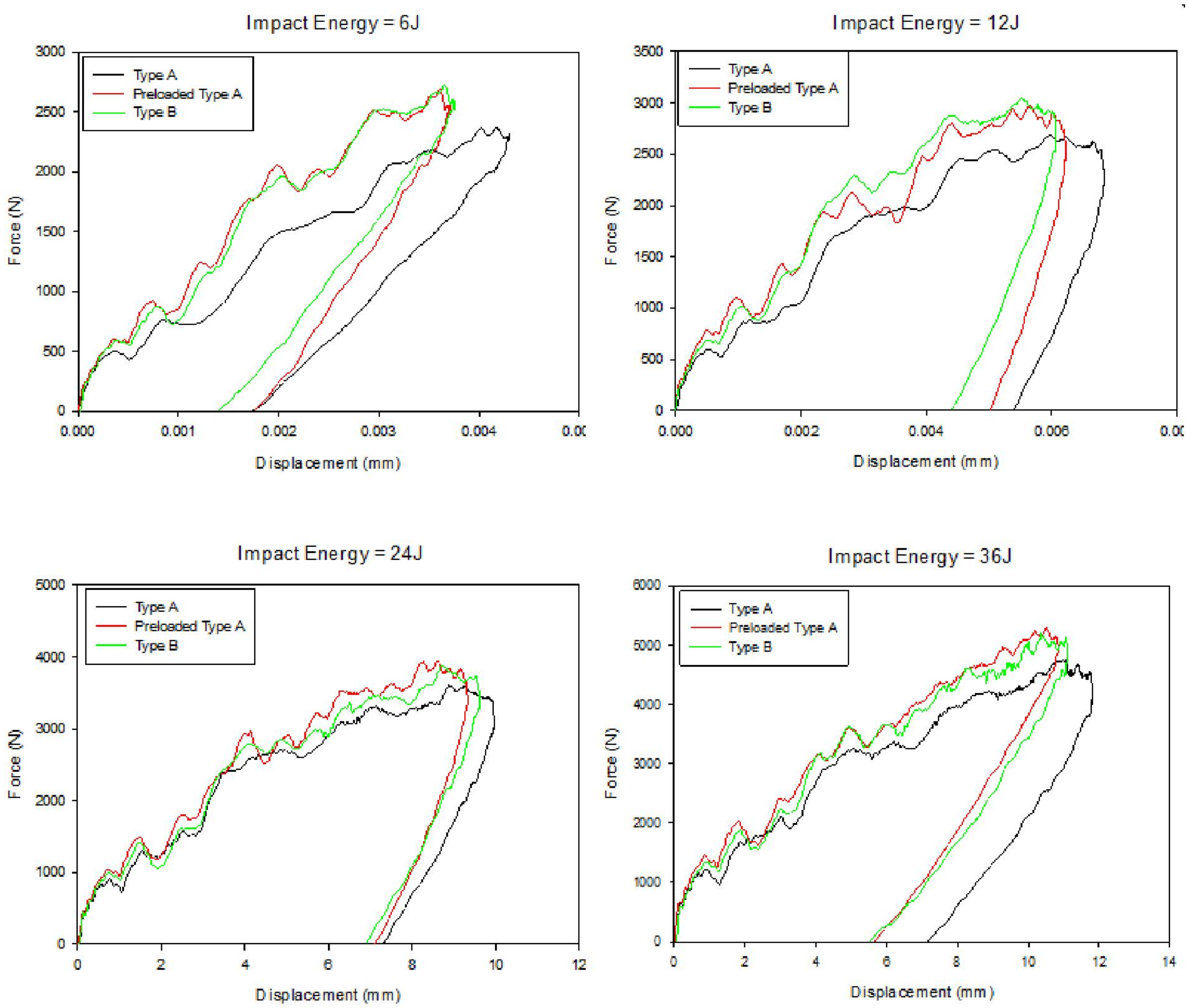

Figure 3. Force versus impactor displacement for impact energies of: 6J, 12J, 24J, and 36J

The effect of pre-stress and curvature on damaged area is shown in Figure 5. The effect of curvature and pre-stress on the damaged area is completely visible from this figure. By applying preload the curvature and pre-stress increased in the laminate (Preloaded Type A) and so damaged area increased. For understanding the contribution level of pre-stress and curvature in this situation "Type B" specimens were provided that its curvature is the same with "Pre-loaded Type A", but does not have pre-stress. As shown in the Figure 5, the damaged area in "Type B" specimen is much more than "preloaded Type A" that means preloading could decrease the damage in the laminate. This result is very important in designing of structures containing composite components. When in a specific structure, a curved laminate composite should be used, by applying a pre-stress this part will be more safe under impact loadings. Comparing the damaged area of the Type A and Type B specimens shows the effect of curvature. According to Figure 4 and 5 the maximum force and damaged area increase and maximum displacement and time-duration of impact decrease by increasing the curvature.

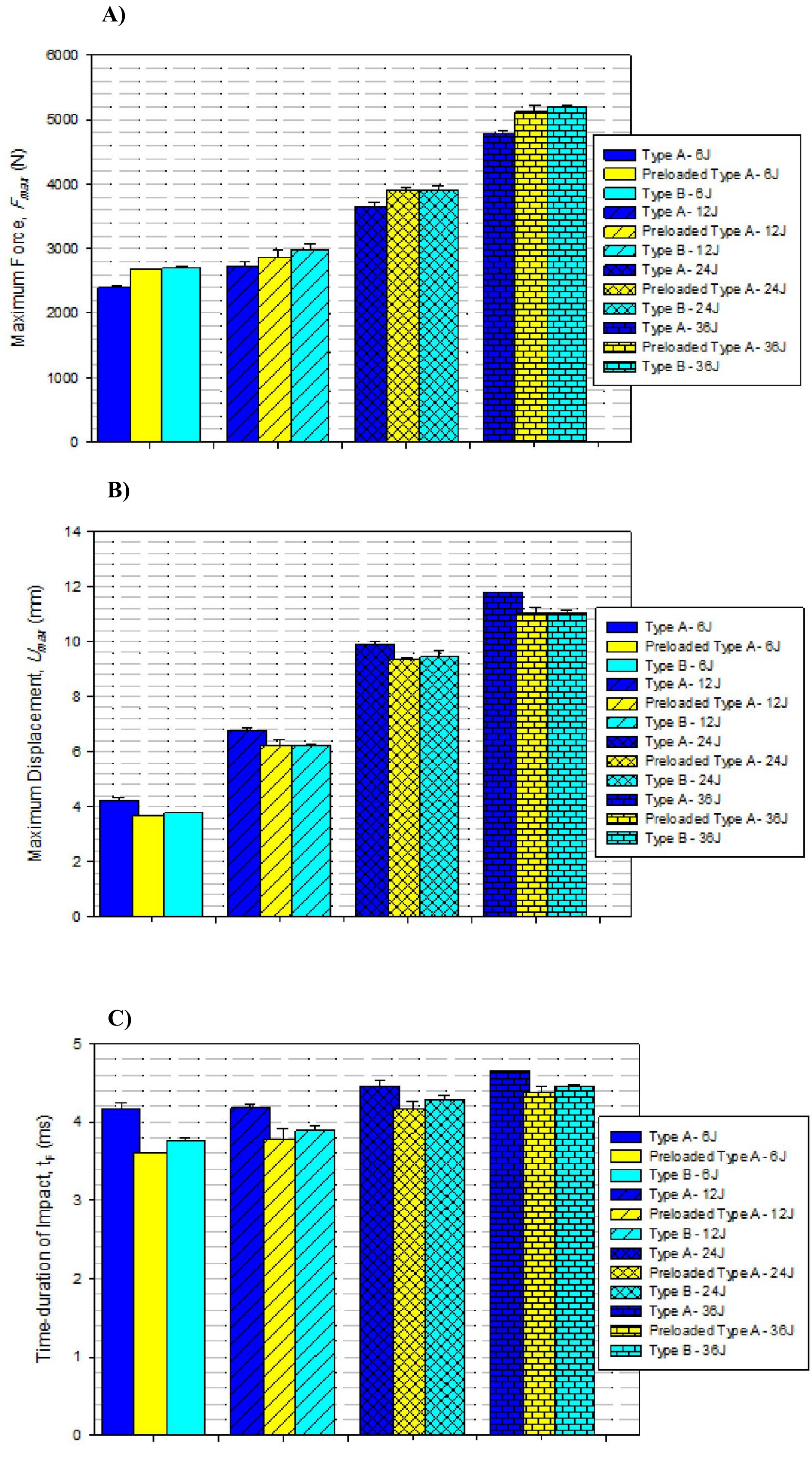

Figure 4. The effect of different configuration on: A) maximum load B) maximum displacement and C) time-duration of impact

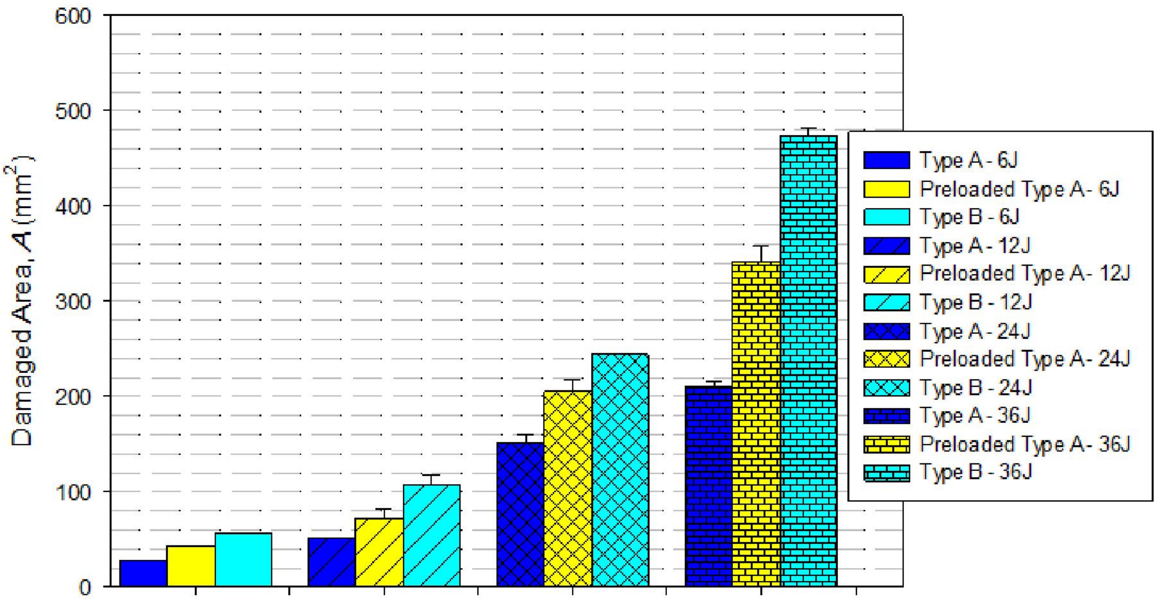

Figure 5. The effect of different configuration on damaged area

Table 1 presents more details about the effect of curvature and pre-stress on damaged area. As shown, decreasing the radius of curvature from 190mm (Type A) to 125mm (Type B) increases the damaged area about 100% in various impact energies. On the other hand, by applying pre-stress on the specimens (Preloaded Type A) the damaged area increased in the range of 36% to 62% in different impact loading. Comparing the results of "Preloaded Type A" and "Type B) shows the effect of pre-stress, while the curvature of both samples of them is the same. It shows that the pre-stress, decreased the damaged area from -16% to -32% in different impact energies.

	6J			*12J*		
	TYPE A	PRELOADED TYPE A	TYPE B	TYPE A	PRELOADED TYPE A	TYPE B
DAMAGED AREA	27.3	43	57	51	72	107
VARIATION (%)	--	+57.5	+109	--	+41	+110

	24J			*36J*		
	TYPE A	PRELOADED TYPE A	TYPE B	TYPE A	PRELOADED TYPE A	TYPE B
DAMAGED AREA	151	205	244	211	342	473.5
VARIATION (%)	--	+36	+92	--	+62	+124

Table 1. Damaged area in different configuration under various impact energies

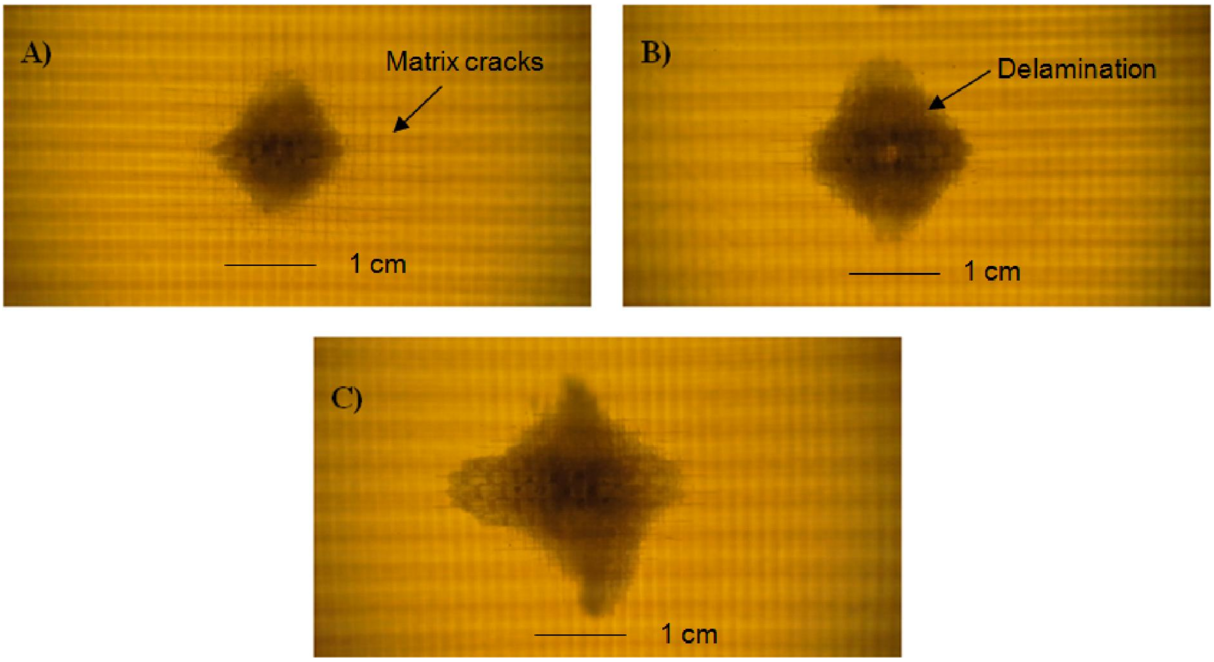

Figure 6. The damaged area of: A) Type A B) Preloaded Type A C)Type B specimens under 36J impact energy

The damaged area of the “Type A”, “preloaded Type A”, and “Type B” specimens under 36J of impact energy is illustrated in Figure 6. According to these pictures, matrix cracks and delamination are the failure mode of the specimens under this impact energy. The configuration of the specimen also affect on the shape of the damage. While the shape of damage in “Type A” and “Preloaded Type A” are rhombic like, the damaged area of the “Type B” specimen is almost irregular. With the first glance in the pictures, it is obviously possible to understand that the matrix cracks in the “Type A” specimens are much more than two other configuration.

4. Conclusion

In this research the effect of pre-stress and curvature on the impact behavior of curved laminates were investigated. Three different specimens were prepared for this goal: 1- “Type A” that its initial radius of curvature was 190mm and without pre-stress. 2- “Preloaded Type A” that was under pre-stress and its radius of curvature was 125mm during the impact test. 3- “Type B” that its initial radius of curvature was 125mm and without pre-stress. According to the outcomes obtained from the impact tests following results can be concluded:

1- Increasing the curvature increased maximum force and damaged area, while decreased the maximum displacement and time-duration of impact.

2- Comparing the results of “Preloaded Type A” and “Type B” specimens showed that pre-stress could decrease the damaged area significantly. This result is very important for designing the structures containing curved composite laminates.

3- The pictures of damaged area shows that matrix cracks and delamination are the failure modes of impact tests and matrix cracks is more in “Type A” specimen, whereas the delamination area of the two other specimens are more.

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