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THERMO-AGING EFFECT ON THE BUCKLING BEHAVIORS OF U-NOTCHED COMPOSITES

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Abstract— *In this study, thermo-aging effect on the U-notched composite plates were investigated experimentally. The temperature, time and notch geometry variations were analyzed. The eight layered woven glass fiber reinforced epoxy matrix resin composite plates were subjected to different temperatures and different time intervals. During the thermo-aging process, the composite plates were subjected to 80, 120 and 160^{o}C temperatures while time intervals were varied to 2, 4 and 6 hours. Considering the notches geometry, the variations at the depth of the notch were taken as 0, 5 and 10 mm. The critical buckling load results of thermo-aged composite plates were compared to the composite plates which were produced at the room temperature. The results of study showed that the critical buckling loads of composite plates were decreased 34.61%, 11.8%, 14.63 % with an increase at the notch depth, temperature and time, respectively.*

Keywords— Thermo-aging, composite plates, notch effect, buckling.

1. Introduction

Composite materials can be produced according to the designed purposes unlike conventional metallic materials. The composite materials are preferred in the aviation and marine vehicles due to their rigidity, high corrosion strength and lightness. Also, the mechanical properties of composite materials were varied according to the intended use. The conventional materials 'like steel' have been used for a long time, therefore, the time dependent thermo-mechanical properties of these materials have been investigated and known well. Also, this material was had the international standard. However, the composite materials still need to be investigated because of their mechanical properties are complex and cannot be known well in different conditions such as effect of external conditions change. Especially, effects on the mechanical properties of the composite material with increasing temperature is an issue to be investigated. Recently, time dependent temperature effect and environmental effect on the composite materials have been investigated. Belaid et al. were investigated thermal aging effect on the glass fiber reinforced polyester resin composite plates with experimental and numerical methods [1]. In the aging process, the composite plates were kept at constant temperature of 80^{o}C during 30, 60, 90 and 120 days. Depending on the increase of aging time, they were determined that the modulus of elasticity and tensile strength were decreased 50 % and 22%, respectively. The temperature and humidity effect on the interfacial shear strength were investigated by Ray [2]. The carbon and glass fiber reinforced epoxy matrix resin composite plates were used in the experimental study. The interfacial shear strength of composite materials was determined by short beam shear test methods. It was observed that the temperature and absorbed moisture were increased, the interfacial shear strength was decreased. Allock et al. were investigated temperature effect on the mechanical properties of composite plates, experimentally [3]. For this purpose, dynamic and static tensile tests were carried out at temperatures ranging from -40 ° C to 140 ° C. Depending on the increase of temperature, it was determined that the static and dynamic modulus of elasticity, and tensile strength of composite plates was decreased.

Increasing short-term temperature effect on the mechanical properties of composite plates was investigated with experimentally by Péreza et al. [4]. The composite specimens were exposed to different temperature (150ºC – 350ºC) changing from 60 to 180 seconds. The experimental study was realized at static tensile test and charpy test. It was observed that, when the temperature was increased from 25ºC (room temperature) to 200ºC, the tensile strength and absorbed energy were increase. Also, when the temperature was increased from 200ºC to 350ºC, the tensile strength and absorbed energy were decreased. Long-term temperature increasing effect on the interfacial shear strength of composite plates was investigated by Ray with experimental study [5]. Experimental study was realized at short beam shear tests. In the thermal shock processing, the specimens were waited at 5, 10, 15 and 20 minutes with 50ºC constant temperature, then these specimen's temperature were dropped -20ºC. It was determined that, the interfacial shear strength was increased depending on the wait time. Mouzakis et al. were investigated temperature, moisture and UV radiation effect on the mechanical properties of composite materials [6]. In the experimental study, static tensile test and three-point bending test were applied on specimens. At the end of the aging process, the tensile strength was increased, however the extension and modulus of elasticity was decreased. Critical buckling loads of composite plates which had central circular hole were investigated by Baba and Baltacı with experimental and numerical methods [7]. Support type, layer arrangement and plate length effects on the critical buckling loads were analyzed. Kömür et al. were researched critical buckling loads of composite plates with central elliptical cut-out by numerically [8]. Critical buckling loads of different edge-notched composite plates were analyzed by Tercan and Aktaş with experimentally and numerically [9]. Buckling behavior of U-notched thermoplastic composite plate were studied Yazıcı et al. by experimental and numerical methods [10]. Akbulut and Sayman were analyzed different edge notch effects on the critical buckling load of composite plates by using the finite elements method [11]. Topal and Uzman were investigated critical buckling loads of composite plates which had thermally loaded [12]. The effect of temperature on the critical buckling load of the composite plates were investigated by Jones with analytical methods [13].

The main objective of this study is to investigate the critical buckling loads of composite plates which are exposed to undesirable high temperatures at particular times. For this purpose, the composite plates were exposed to different temperatures at varied time period. The first group of samples were waited 2, 4 and 6 hours at a constant temperature of 80ºC. The second group of samples were waited at the temperatures of 80ºC, 120ºC and 160ºC at a constant time of 4 hours. The third group of samples were waited at the room temperature and used as a control group. The results were presented in tables and graphs.

2. Experimental Study

Experimental study was performed in three steps. In the first step, the specimens were dimensioned and their edge notches were opened. In the second step, temperature at certain times on the samples was applied. In the third step, experiments were performed to determine the critical buckling load of the specimens. Geometric model and boundary conditions of the problem were presented in Fig. 1.

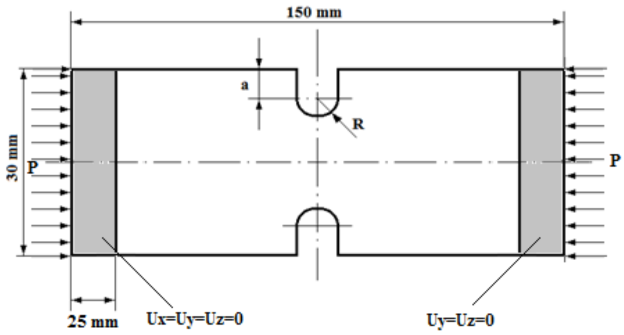

Figure 1. Geometry and boundary conditions of problem.

In the Fig. 1, P was represented load (N), Ux, Uy, Uz were represented support types. Un-notched (str.), semi-circular edge notched (U 0) and U-notched (U 5) composite plates have been used as three different geometries in the solution of problem. Un-notched (str) was represented the composite plates having any notch. The semi-circular notch was represented composite plates which was consist of notched and a=0 mm. Also, the U-notch was represented composite plates which was consist of notched and a=5 mm. Determining the effect of temperature effect, the specimens were exposed to 80°C, 120°C and 160°C at 4 hours. In addition to this, the time was varied as 2, 4 and 6 hours at a constant temperature of 80°C. Further, extra samples with the same geometry were waited at room temperature to compare the effect of different conditions on the results. In the room temperature conditions, the temperature was accepted as 25°C and time was accepted as 0 hour. All of the specimens were waited in the same room and moisture rate. Thus, the effect of moisture rate was neglected in this study. Geometric changes and temperature conditions of the problem was showed in Table 1.

Table1. Geometric changes and temperature conditions of the problem.

Type of Specimens	**Represent**	**a /R (mm)**	**Time (hour) (Temperature= 80 °C)**	**Temperature (°C) (Time= 4 hour)**
Un-notched	Str	0/0	0^{*}, 2, 4, 6	25^{**}, 80, 120, 160
Semicircular Notched	U 0	0/5	0^{*}, 2, 4, 6	25^{**}, 80, 120, 160
U Notched	U 5	5/5	0^{*}, 2, 4, 6	25^{**}, 80, 120, 160
*: Time (0 hour), **: Room temperature (25°C)				

The composite plates with a width of 30mm and a thickness of 2.5mm were provided from Izoreel Company. They were cut at length of 150mm and the notches were opened with milling cutter. Then, temperature was applied to the specimen with the aid of oven which have ±3 °C thermostat and time control was realized with chronometer.

At the end of the experiment, the critical buckling loads were obtained from the load-extension graphs. The critical buckling load was taken into account when the load-extension graph value was diverged to the linear point. Fig. 2 shows the buckling of composite plate and the determination of the critical buckling load.

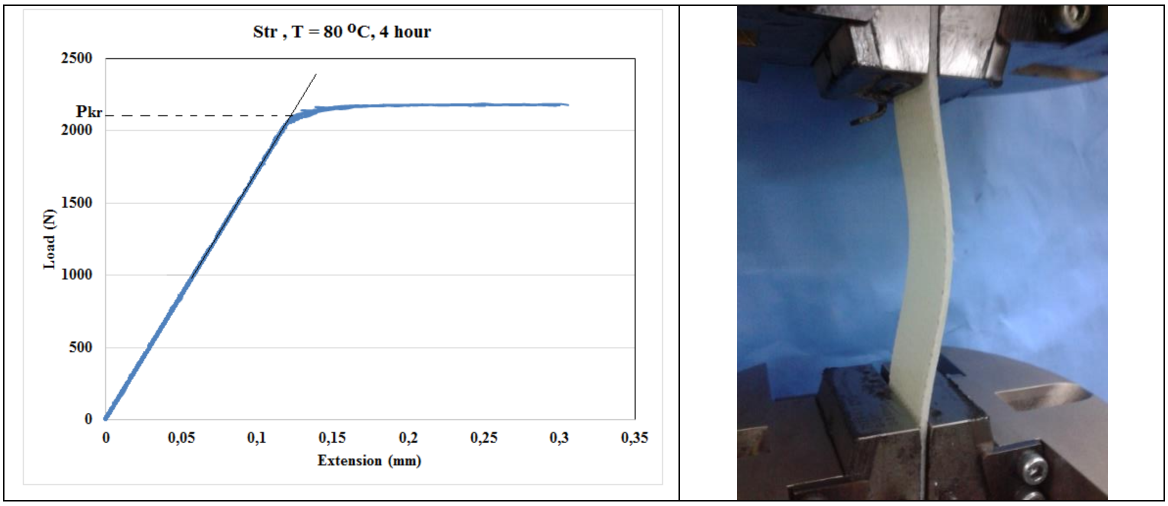

Figure 2. The buckling of composite plate and the determination of the critical buckling load.

3. Results and Discussions

In this study, the critical buckling load of notched and un-notched composite plates were determined for different temperatures and times experimentally. the three different geometries (str, U0 and U5), the four different temperatures (25, 80, 120 and 160ºC) and the four different waited time (0, 2, 4 and 6 hours) were used. This study was presented in two sections: First, temperature was increased for a constant time. Following, time was increased for a constant temperature.

3.1. The effect of temperature increase on the critical buckling load

The samples were waited 4 hours in the oven at 25ºC, 80ºC, 120ºC and 160ºC to determine the temperature effect on the critical buckling load of composite plates. Fig. 3 shows the effect of temperature on the critical buckling load of composite plates.

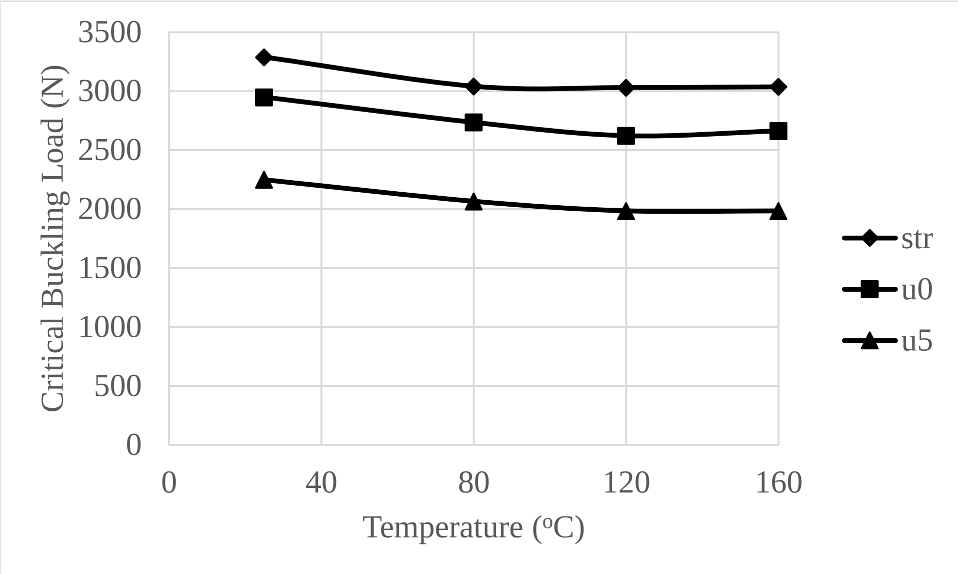

Figure3. The effect of temperature on the critical buckling loads of composite plates.

As seen in the Fig. 3, the critical buckling loads of all notch types were decreased with increase in temperature from 25ºC to 160ºC. The maximum critical buckling load was obtained for the str type specimen as 3287.15 N waited in room temperature while the minimum critical buckling load was obtained for U5 type specimen as 1983.16 N waited in 160ºC. When these results were compared with room temperature results, the maximum decrease rate of critical buckling load was occurred as 11.8% for U5 type at the temperature of 160ºC. While the minimum decrease rate of critical buckling loads was obtained for the str type as 7.48% at the temperature of 80ºC. The decrease rate of the critical buckling loads for other specimens were presented in Tab. 2.

Table 2. The decreasing rate of critical buckling loads for increasing temperature according to room temperature.

Temperature (ºC)	Str (%)	U 0 (%)	U 5 (%)
80	7.48	7.84	8.10
120	8.48	11.07	11.78

160	7.62	9.72	11.80

The results of U0 and U5 type specimens were compared with results of str type specimen to investigate the notch type effect on the critical buckling load. The decreasing rate of critical buckling loads were presented in Tab.3.

Table3. Notch type effect on the critical buckling loads.

Temperature (ºC)	U 0 (%)	U 5 (%)
25	10.29	31.59
80	10.06	32.09
120	13.47	34.50
160	12.31	34.61

The maximum decrease rate of critical buckling loads was obtained for U5 type at 160ºC as 34.6%. In addition to this, the minimum decrease rate of critical buckling loads was obtained for str type at 25ºC (room temp.) as 10.29%.

3.2. The effect waiting time on the critical buckling load

The samples were waited 2, 4 and 6 hours in the oven at a constant temperature of 80ºC to determine the waiting time effect on the critical buckling load of composite plates. Fig. 4 shows the effect of waiting time on the critical buckling load of composite plates.

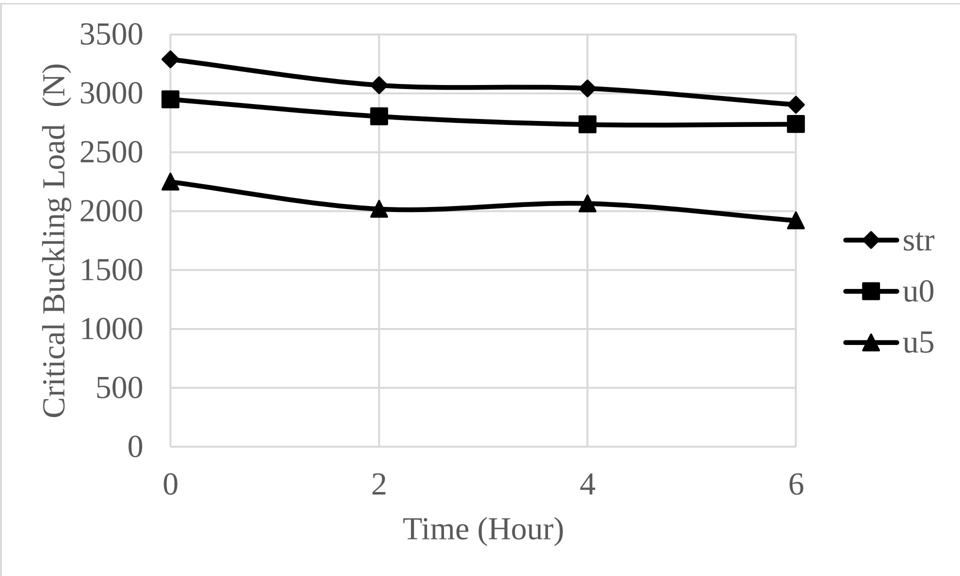

Figure 4. The effect of increase in waiting time on the critical buckling loads of composite plates.

As seen on the Fig. 3, the critical buckling loads of all notch types were decreased for increasing waiting time from 0 to 6 hour. The maximum critical buckling load was obtained for str type specimen which was waited in room temperature as 3287.15 N. Also, the minimum critical buckling load was obtained for U5 type specimen as 1919.67 N which was waited in 6 hours. When these results were compared with room temperature results, the maximum decrease rate of critical buckling loads were obtained as 14.63% for U5 type waited for 6 hours. In addition, the minimum decrease rate of critical buckling loads was obtained as 6.67% for str type waited for 2 hours. The decrease rate for other specimens were can be seen in Tab. 4.

Table 4. The decreasing rate of the critical buckling loads for increasing waiting time.

Time (Hour)	Str (%)	U 0 (%)	U 5 (%)
2	6.67	4.91	10.23
4	7.54	7.21	8.18
6	11.7	7.14	14.63

The results of U0 and U5 type specimens were compared with results of str type specimen to investigate the notch type effect on the critical buckling load. The decreasing rate of critical buckling loads was presented in Tab.5.

Table 5. Notch type effect on the critical buckling loads (for waiting time changing).

Time (Hour)	U 0 (%)	U 5 (%)
0	10.29	31.59
2	8.59	34.21
4	10.06	32.09
6	5.67	33.85

The maximum decreasing rate of critical buckling loads was obtained as 34.21% for U5 type waited for 2 hours while the minimum decrease rate of critical buckling loads was obtained as 5.67% for U0 type waited for 6 hours.

4. Conclusions

In this study, the thermo-aging effect on the critical buckling load of U notched composite plates investigated. The results can be summarized as below:

- When the temperature was applied on the composite plates, the critical buckling loads of composite plates were decreased.
- The critical buckling loads of composite plates could be affected the notch type changing.
- The waiting time with high temperature was played an important role.
- When a composite part is designed, the designer must take into account of the environmental temperature.

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