JOURNAL OF SCIENCE
SAKARYA UNIVERSITY

Sakarya University Journal of Science

ISSN 1301-4048 | e-ISSN 2147-835X | Period Bimonthly | Founded: 1997 | Publisher Sakarya University | http://www.saujs.sakarya.edu.tr/

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Recieved: 2019-02-18 00:00:00

Accepted: 2019-03-11 00:00:00

Article Type: Research Article
Volume: 23
Issue: 5
Month: October
Year: 2019
Pages: 749-754

How to cite
Seçil Ekşi, Kenan Genel; (2019), Numerical And Experimental Investigation Of Bending Behavior Of Pre-Stressed Aluminum Tube . Sakarya University Journal of Science, 23(5), 749-754, DOI: 10.16984/saufenbilder.528549
Access link
http://www.saujs.sakarya.edu.tr/issue/44066/528549

Sakarya University Journal of Science

Sakarya University Journal of Science 23(5), 749-754, 2019

Numerical and Experimental Investigation of Bending Behavior of Pre-Stressed Aluminum Tube

Seçil EKŞİ[*1], Kenan GENEL[2]

Abstract

The effect of the pre-stress and internal Pa6 (cast-polyamide) material on the bending behavior of the aluminum tube is investigated experimentally. Finite element studies have been carried out to better understand the effect of pre-stress on the cross-section of tube and to shed light on the experimental studies. From the simulation studies, it was concluded that the effect of the pre-stress on the load carrying capacity of the tube is limited. After finite element studies, experimental studies were performed. In experimental studies, the lower cross-section of the tube was subjected to 175 MPa stress corresponding to 93% of the yield strength of the material. The tensile stress in the tube during the loading is reduced by applying pressure to the lower cross section of the tube beam. In addition, a change in the load carrying capacity of the tube was investigated using a Pa6 ring to delay local buckling. As a result of the experiments, it was found that the pre-stress significantly improved the bending behavior of the tube in the elastic region, while reducing buckling displacement. Application of both pre-stress and internally reinforcement enhanced bending performance of the tube in both elastic and plastic regions. Load carrying capacity of pre-stressed and internally reinforced tube was increased 1.67 times according to the base tube.

Keywords: pre-stress 1, tube 2, bending 3, finite element analysis 4

1. INTRODUCTION

It is known that pre-stressing is widely used in the construction sector. In reinforced concrete structures, the concrete is given a pre-stress to reduce the tensile stress in concrete under service loads or to a certain extent. Pre-stressing is also used in bridges, steel structure, underwater structures, prefabricated structures, towers, beams, buildings, etc. There are many studies on pre-stressed materials and structure used in the construction sector [1-4]. Zhu et. all investigated bending behavior of aluminum I-beams with carbon fiber reinforced plastic (CFRP) tendons by

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pre-stressed. They report that pre-stress increase the bending rigidity and decreases the flexure. Improvement in yield load is at a level of 33.3%. Maximum improvement in failure load of aluminum beam is about 52.3% [1].

There are limited number of studies on pre-stressed tube beams. Bending, impact and wear behavior of pre-stressed tube structures are investigated in some studies (5-8]. Zeinoddini and his friends investigated the behavior of axially pre-loaded steel tubes subjected to lateral impacts experimentally and numerically. They reported that axially pre-loads decrease the lateral impact loads [5]. Firouzsalari and Showkati investigated bending behavior of pre-compressed specimens under local lateral loads experimentally and numerically. They found good correlation between numerical simulation and experimental study. As a result of their study they reported that the final tube strength and the amount of absorbed energy depends on axial compressive preloading. When axial compressive preloading increase, final tube strength and absorbed energy capability decrease under lateral loads [6]. Zhi and his friends studied on axially preloaded circular steel tubes subjected to transverse low-velocity impact experimentally. Bending behavior and lateral collapse capacity of tubes are enhanced with axial tension. Axial compression has a significant effect on collapse capacity of tubes [7].Guan and his friends investigated the impact wear behavior of Inconel 690 alloy tubes with initial pre-compressive stress load. They reported that tube deflection decreased with increasing pre-stress. Contact peak force, wear scar areas and material rigidity increased with increasing pre-stress. Absorbed energy capacity of tubes gradually decreased before the reaching the equilibrium [8].

In this paper, we present effect of the pre-stress and internal Pa6 material reinforcement on the bending behavior of the aluminum tube.

2. SIMULATION STUDY

Three-point bending simulations of the aluminum tube were performed with using Ansys 16. Analyzes were carried out using a quarter-symmetric model of the tube. 10580 20-node Solid 95 quadratic elements and 44318 nodes are used in analyses for the aluminum tube, supports and the loading punch. Contact mechanics between the support/beam and punch/beam interfaces, CONTA174 3-D8-node contact elements are used. The coefficient of friction between the contacting surfaces is taken as 0.2.

The diameter of the tube used in the analyses is 31 mm, the wall thickness is 1 mm and the length is 270 mm. Yield and tensile strength of aluminum tube are 187 MPa and 247 MPa, respectively. The pre-stress process is defined by applying pressure to the lower and quadrant sections from the two ends of the tube structure. The application of constant pressure to the lower sections of the tube beam is shown in Figure 1 together with boundary conditions.

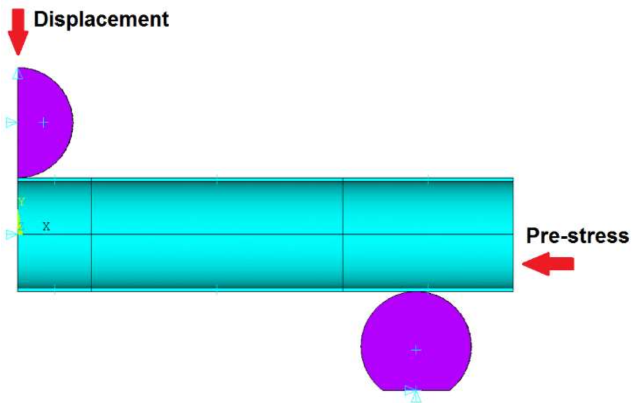

Figure 1. Finite element model and boundary conditions of pre-stressed tube

3. EXPERIMENTAL STUDY

The apparatus for pre-stress application to the tube is designed (Figure 2). In this apparatus, the load is applied to the tube body with of steel wires located between the load cell and the nut. One side of the tube is placed on the cover which is fixed on the main body. The steel tension wire passing through the tube (∅ 6 mm) is connected to the torque bolt at the other end of the assembly. Here the bolt is tightened using the torque spanner so that the gap of the wire is taken, and then the bolt movement is continued until the specified loads value is read in the load cell. For a given tube diameter, foreseen load and therefore for the pre-stress in the section, a torque value must be read in the torque spanner. The tube fixed at one end will be compressed from the other end to the desired torque with the bolt-nut connection, then moved to the three-point bending tester by separating it with the detachable caps shown in the picture on the frame. The diameter, wall thickness and length of the aluminum tube used in the experiments are as follows; 30 mm, 1 mm and 270 mm. The material of the aluminum tube is 6063-T6. Yield strength is 187 MPa and tensile strength is 247 MPa.

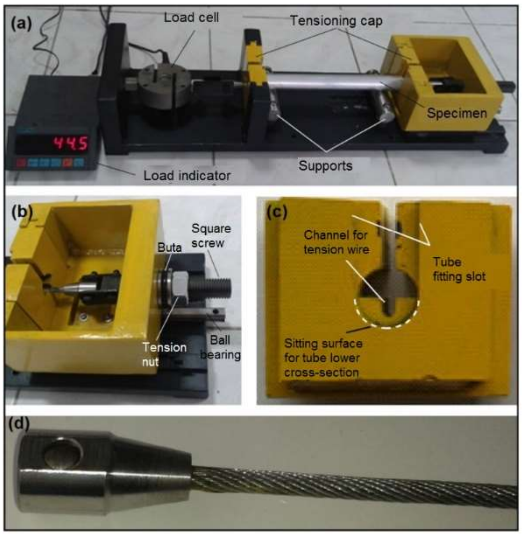

Figure 2. The pre-stress apparatus: (a) General view, (b) Detail view of the drive side, (c) Clamping covers (d) 6 mm diameter steel wire and conical head used in the tensioning process

The test on the three-point bending test machine with the pre-stress device is given in Figure 3.

Figure 3. Test on three point bending machine with pre-stress device

4. SIMULATION RESULTS

The load-displacement curves of tubes obtained from finite element analyses are shown in Figure 4. When the figure is examined, it is seen that when 100 MPa pre-stress is applied to the lower half section of tube, the load carrying capacity of the tube decreases, the buckling displacement value decreases, and the rigidity increases slightly. When pre-stress is applied to the lower quarter section of tube, the load carrying capacity is slightly increased compared to base tube. Bending rigidity and energy absorbing capacity of the tube structure increased in the elastic region.

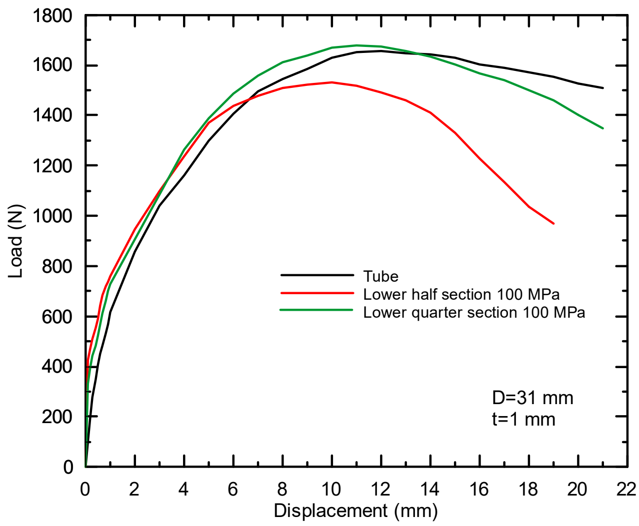

Figure 4. Load-displacement curves obtained from quarter and half section pre-stressed tubes analyses

The results of the analyses carried out at different pre-stress values applied to the lower quadrant of tube are given in Figure 5.

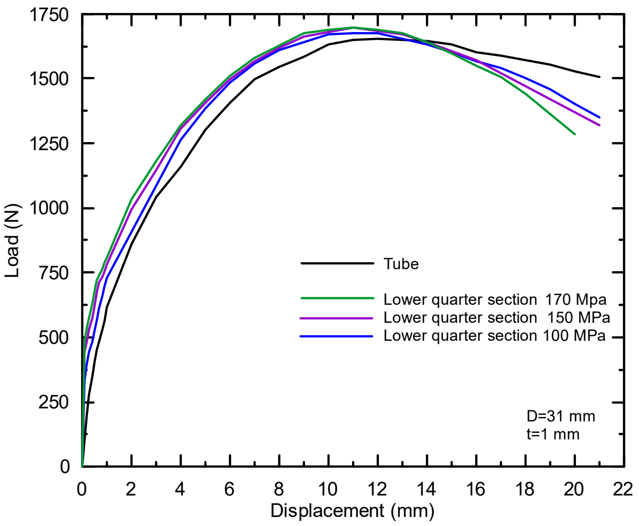

Figure 5. Load-displacement curves obtained from quarter section pre-stressed tubes analyses

When the values of the pre-stress at lower quarter section of tube is changed, it is seen that the load carrying capacity and rigidity of tube changed in insignificantly. When a comparison is made between the models with the 100 MPa pre-stress at the lower half section of tube and the base tube model, yield stress in the lower wall of tube is seen in base tube at 12 mm displacement and the buckling takes place. In the pre-stressed tube, the buckling displacement decreased to 9 mm, but in the lower wall, the yield displacement increased to 14 mm.

The von-Mises stress distribution for the pre-stressed (lower half section 100 MPa) and the base tube models for the displacements (9 and 12 mm) at which the greatest load is obtained in the models is given in Figure 6. When these stress distributions are compared, the distinction between stresses in the lower wall is remarkable. Considering that the yield strength of the tube material is 187 MPa, it is understood that the yield in the pre-stressed tube occurs only in the upper half of the section.

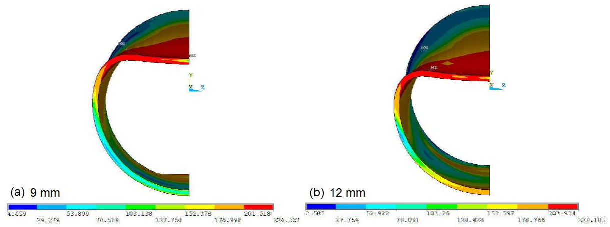

Figure 6. (a) Stress distribution (displacement 9 mm) in pre-stressed model (lower half section 100 MPa), (b) Stress distribution (displacement 12 mm) in base tube model

5. EXPERIMENTAL RESULTS

In the simulation studies, the application of pre-load to quarter-section was performed by defining the pressure directly to the forehead of tube. However, in the experimental study, it is not possible to apply the pre-stress on the steel cord to the lower quadrant homogeneously. Because it passes very close to the bottom wall of the cord. This is an obstacle to perform the experiment. Accordingly, experiments were planned for the application of the pre-stress to the lower half-section of the tube. Diameter of tube used in experiments is 30 mm with 1 mm thickness. In three point bending tests, Pa6 ring was placed to the tube in order to prevent the local deformation on the surface of tube. Width of Pa6 ring was determined equal to the diameter of the mandrel (D:30 mm). The ring was prepared as a tight fit. Loads applied to the tube structure did not exceed the yield strength in the wall. Loads did not cause buckling. The optimal upper stress value was determined as 175 MPa for the initial preload of 7745 N. The axial load on the tube lower cross section through the steel cord and the bending load applied to the tube during the experiment to obtain the pre-stress is obtained simultaneously with the two load cell is given in in Figure7. Initially, the pressure of 175 MPa is applied to the bottom wall of the tube with the steel cord under the pre-load of 7745 N. With increasing displacement, the displacement value of 4.6 mm is reached in 8080 N. The tensile stress at this load value is 177.3 MPa, which is less than yield strength of aluminum (187 MPa)

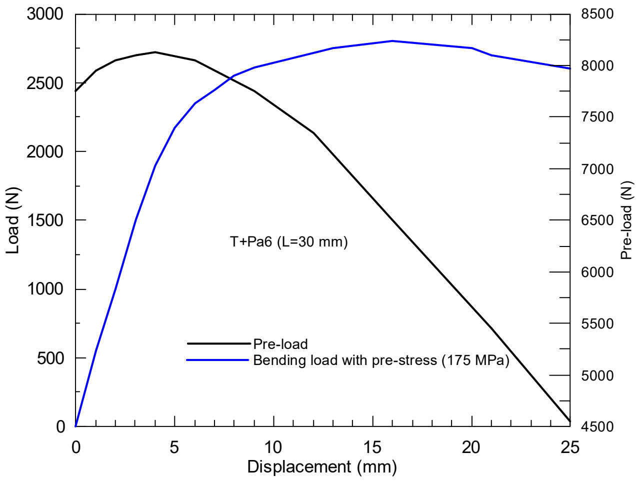

Figure 7. Pre load and bending load – displacement curves

The pre-loading value of the cord quickly decreases with increasing displacement and the bending load starts to emerge because the movement in the pre loading equipment is limited in the channel where the cord moves. The load measurement on the cord was stopped by interfering to the experiment.

The results of experiments are given in Figure 8. Pre-stress did not provide a significant improvement on base tube structure. The maximum load carrying value of tube structure with Pa6 ring, which has an initial pre-stress value of 175 MPa, increased slightly to 2808 N with an increase compared to the non-pre-stress state (2717 N). Bending rigidity of tube structure has increased significantly. Energy absorbing capability of tube has also increased. When the buckling displacement values are examined, the buckling displacement is smaller relative to the non-pre-stressed tube structure. Although improvement has been achieved with respect to the previous pre-stressed condition. It is expected that the buckling displacement will be slightly smaller than the non-stressed condition.

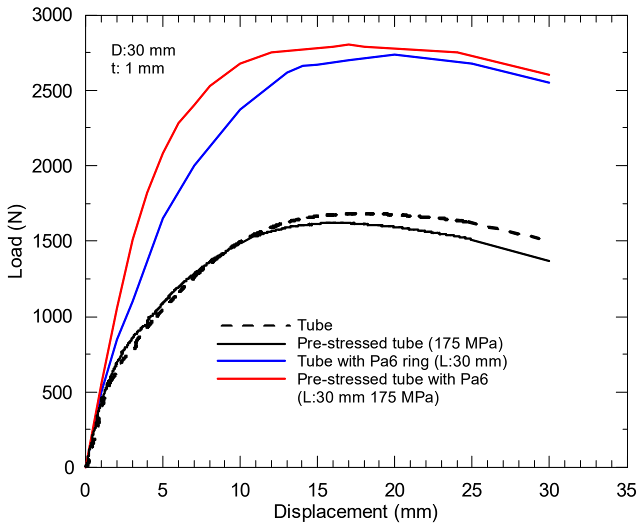

Figure 8. Load-displacement curves of pre-stressed / non-pre stressed and pre-stressed reinforced/non-reinforced tube structures with Pa6 ring

In order to produce a tube with a pre-stressed practical arrangement which can be used in practice, the most simple and light application of the above apparatus is designed as in Figure 9 below.

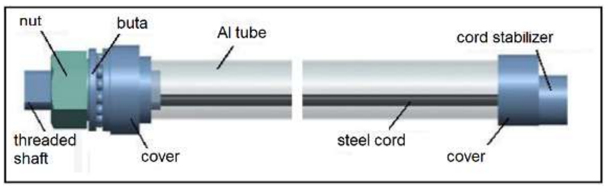

Figure 9. Tube-mounted portable device design for pre-stress application

The minimum weight of this portable design is 610 g for cases where the covers are made of aluminum. Taking into account the obtained load carrying capacity, it is clear that the specific load carrying capacity (2808/610 =) will get a very small value of 4.6. Therefore, the improvement in light weight and load carrying behavior is extremely limited.

6. CONCLUSIONS

The contribution of the applied pre-stress to the load carrying capacity of the tube beam is insignificant and reduces buckling displacement. The pre-stress application with internal reinforcement increases the bending rigidity of the structure in the elastic region and provides some improvement in the load carrying capacity (F_{max}). On the other hand, there was no improvement in terms of specific load carrying capacity, but a decrease of 75% was observed. Load carrying capacity of pre-stressed and internally reinforced tube was increased 1.67 times according to the non-pre stressed internal reinforced tube. It has been found from numerous experiments and obtained results that the improvement provided if a polymeric part equivalent to the additional weight used for the application of the pre-stress is partially inserted into the tube structure is highly preferred over the pre-stress case. It has thus been understood that pre-stress application enhances the rigidity of the elastic region provided that the inner Pa6 ring is used, but this method is expensive and is not very preferred because of the difficulty of the practice.

Acknowledgments

The work described in this paper is supported by TUBITAK (The Scientific and Technological Research Council of Turkey) under project number 110M054.

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