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A Numerical Study of the Induced Stresses in the Separation Points of the Tensile Element (Chain) of the Plate Conveyor Used in the Blowing Unit in Water Factories

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The Induced Stresses in Tensile Element Joints (chain) were Studied in Two Phases: The first phase is to conduct a design study of the plate conveyor to determine the maximum tensile strength to which the joint is exposed. Then build two models, the first one represents a single joint with its components (wedge- copper ring- plate) with the basic dimensions and measurements of the chain. The second model was designed with new dimensions to suit the conveyor's working conditions. In the second phase, the three-dimension finite elements method was used to identify the stresses induced in the joint for both models and then compare the results to identify the model that shows the best performance. The result showed that increasing the external thickness of the joint by double in the proposed model up to the value of 6 mm was able to provide a homogeneous distribution of the main induced stress, which contributed to reducing the critical values of these stresses compared to the induced stresses in the model currently used. Consequently, increasing the external thickness of the joint has played an important role in reducing stresses, which leads to an increase the service life of the plate conveyor chain.

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1. INTRODUCTION

Different types of conveying machines are used in factories, construction, agriculture and all national economy facilities to transfer various collapsible materials (sand, coal, etc.) or parts (tubes and machine components) [1]. Some of its types are plate conveyors with a chain tensile element which is used either horizontally or diagonally (30-50°) to perform some technological processes (painting, assembling, monitoring, cooling, heating) as well as transporting process, which generally consists of:

a) **Tensile element:** Which is considered the main and most important part of the conveyors. Any damage caused to it, leads to the suspension of the conveyor.
b) **Moving mechanism:** It is used to provide horizontal movement of the conveying machine. It often consists of steering gear, trajectory, electric motor, reducer (used to increase the torque by lowering engine rotation speed, in order to secure the required transfer or lifting speed.
c) **Tensile mechanism:** As a result of continuous work in water factories, the plate conveyor with a chain tensile element is exposed to degradation concentrated in the separation positions between the chain plates. This comes as a result of repeated concentration of high value stresses at a specified position, leading to failure. In order to identify the values of these stresses and the places of their distribution and concentration, the three-dimensional finite elements technology and Maximum Principle Stress Failure Criteria were employed [2]. This criterion compares the maximum value of the main stress with the maximum tensile stress value of the material. When the maximum principle stress reaches the ultimate tensile stress, the material fails and it is wrong to use it at work [3].

The importance of this research is mainly to highlight the positive change achieved by the adjustment in the dimensions of the tensile elements of the plate conveyor, used within mineral water bottles forming machine (blowing unit) on induced stresses in the joint of the tensile element plates. These were identified using the three-dimensional finite elements method. Thus, the aim of this research is to increase the service age of the plate conveyor by improving the distribution of stress and preventing their concentration in specific areas to prevent failure.

2. MATERIALS AND METHODS

2.1 Finite Elements Model

Two three-dimensional models have been created to build the plate joint using Autodesk® Inventor™. The first model represents the design currently used in the production of tensile element plates, while the second model was designed with new dimensions as shown in Fig. 1, taking into account not to adversely affect the electromechanical work within mineral water bottles forming machine. Elements for FEA were tetrahedrons as shown in Fig. 2.

2.2 Boundary Conditions

Fig. 3 shows one joint of a small plate according to sector (A-A') and the fixation of the cutting surfaces in both models.

During its movement, the chain is exposed to motion resistances are longitudinal gravity force of the material and the longitudinal gravity force of the moving conveyer's parts. Those affect the value of a tension force resulting from the tensile mechanism (air piston) that is placed next to the leading pulley and induced in the chain joints of the conveyor.

The tensile forces are determined at all points, starting from the point where the leading tensile element departs and moves in the direction of the movement of the conveyor according to the following equation: The tensile force at the next point is equal to the sum of the tensile force at the previous point and the motion resistance strength of the part between two the points [4].

$$s_{i+1} = s_i + w_{i-(i+1)} \tag{1}$$

where:

s_{i+1}: The tensile force at the next point.
s_i : The tensile force at the point.
$w_{i-(i+1)}$: The motion resistance strength of the part between two points.

By applying the above equation, the following values were obtained:

$$s_1 = s_{min} = 3859.8\ ,\ s_4 = s_{MAX} = 4226.38\ \text{N}\ ,$$
$$s_2 = 3887.38\ \text{N},\quad s_3 = 4198.58\ \text{N}$$

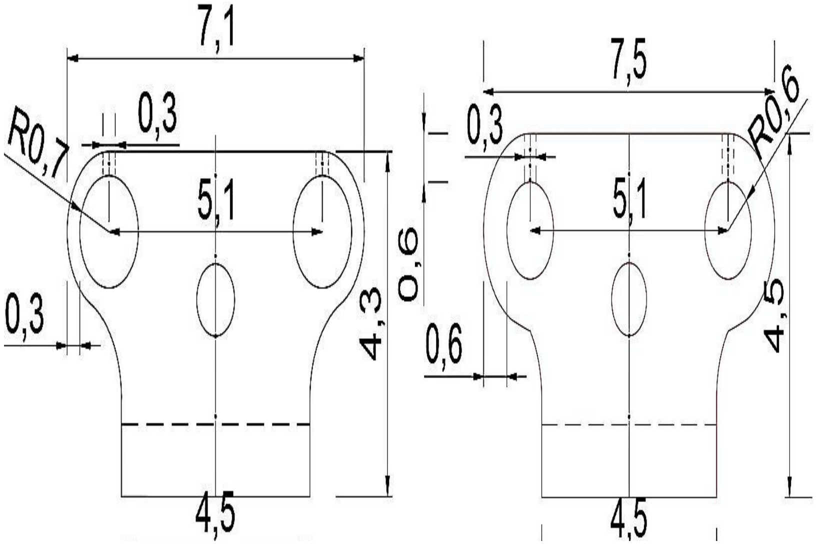
where:

S_1: The maximum tensile strength.
S_4: The minimum tensile strength.
S_2: The tensile strength at the point 2.
S_3: The tensile strength at the point 3.

Thus, the applied load is equivalent to:

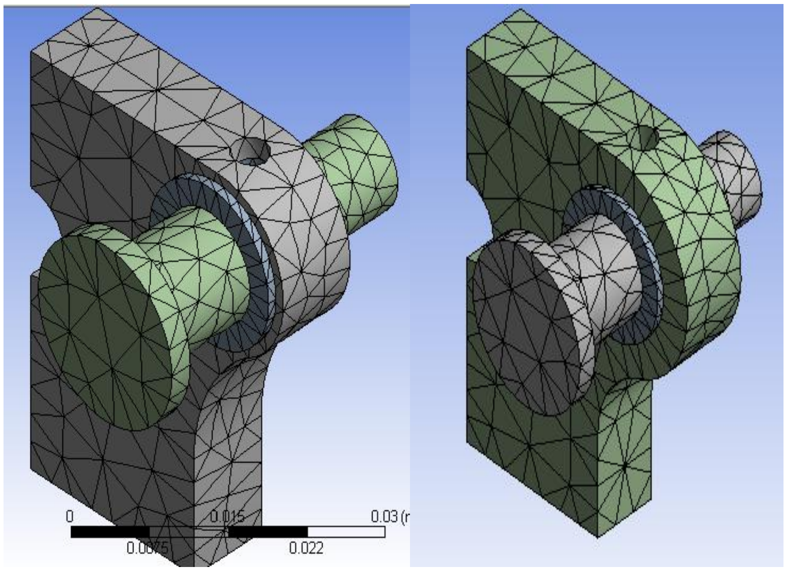
$$f_x = \frac{s_4}{2} = 2113.19\ \text{N} \qquad (2)$$

This is because the chain is double joint. Fig. 5 shows loading surface and applied load.



a) Used model b) Proposed model

Fig. 1. Geometric drawing for the front view of the plate's body



a) Used model b) Proposed model

Fig. 2. Volumetric mesh

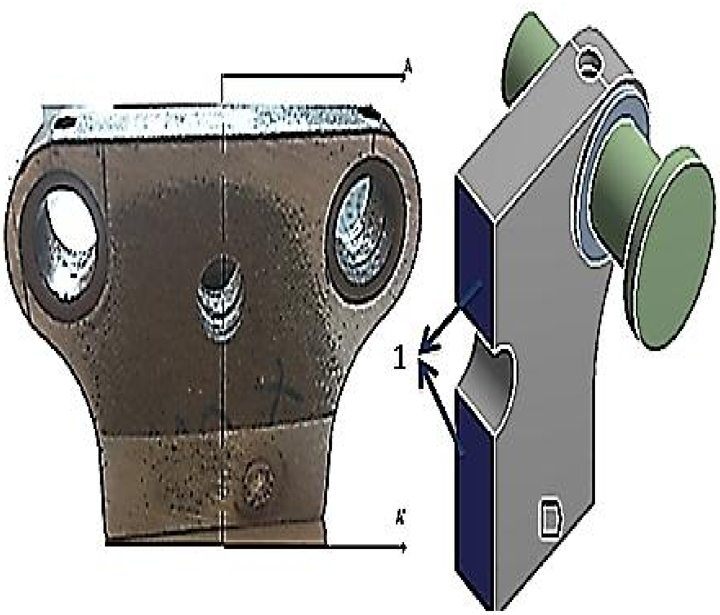


Fig. 3. Fixing surfaces of the analytical model according to the (A-A') sector

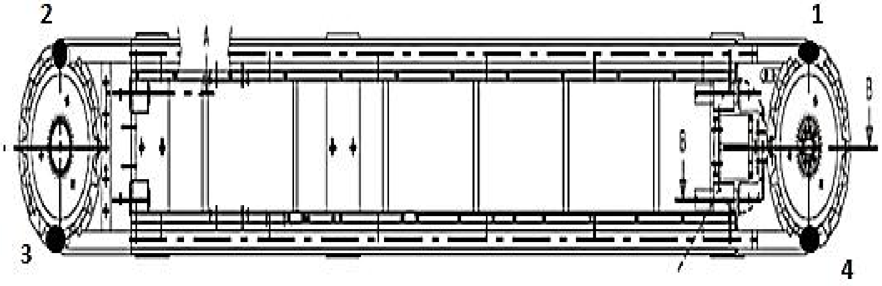
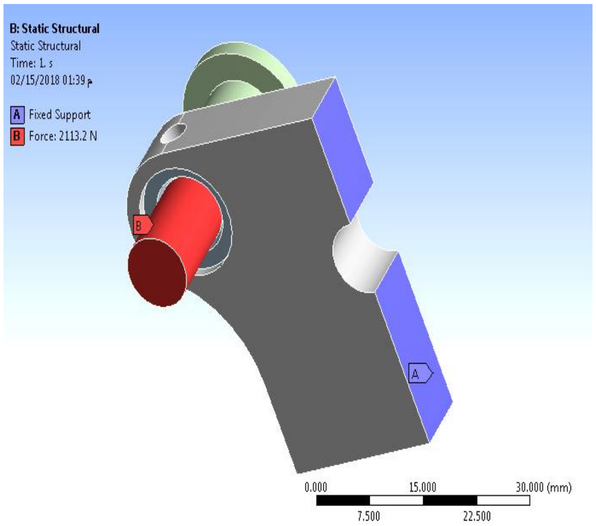


Fig. 4. Front view of the tensile element in the plate conveyor


B: Static Structural
Static Structural
Time: 1. s
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A Fixed Support
B Force: 2113.2 N

Fig. 5. Fixed surfaces and surfaces exposed to load

All contacts were linear and bonded. Fig. 6 shows the first contact area between the outer surface of the copper ring (2) with the inner perimeter of the joint and the inner surface of the plate body (1).

The second contact area was between the internal surface of the wedge (2) with the outer surface of its tangled copper ring as shown in Fig. 7.

2.3 Materials Properties

In the material library in the program, the materials are defined as linear elastic isotropic, by determining the density and chemical composition of the chain joint elements in the technical college laboratory – Tartous University, and selecting the compatible standard alloys. Results are shown in Table 1.

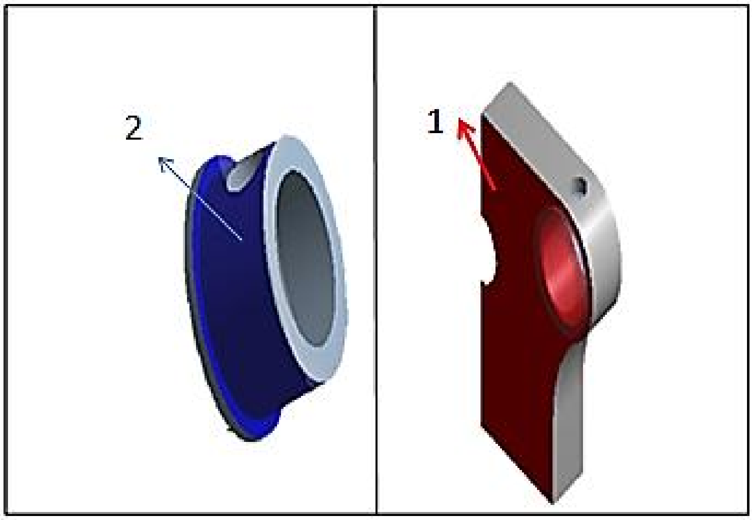

Fig. 6. First contact area

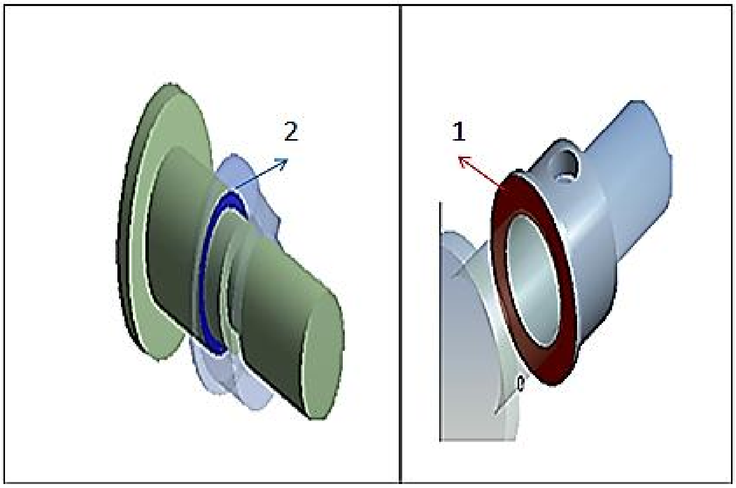

Fig. 7. Second contact area

Table 1. The chemical composition and density of the used chain

Al (%)	Si(%)	Cu (%)	Mg(%)	Density (g/cm^3)	Standard Alloy[5]
98.2	0.426	0.399	0.0461	2.89	ASTM 6063

Table 2. The chemical composition and density of the copper bushing (ring)

Cu(%)	Zn(%)	Pb(%)	Sn(%)	Ni(%)	Density $(\mathrm{g/cm^3})$	Standard Alloy[6]
88	7.5	2.1	0.2	2.8	2.65	Tin Bronze C92600 ASTM (B584)

Table 3. The chemical composition of the wedge

Fe (%)	C (%)	Mn (%)	P (%)	S (%)	Standard Alloy[7]
97.8	0.375	1.26	0.0169	0.0848	AISI 1039

3. RESULTS AND DISCUSSION

The results obtained from the finite elements analysis were clarified in illustrative graphic forms of stress distribution with colored gradient scale, showing the minimum and maximum values of arising stresses in the studied models. Making it possible to compare the studied models in a direct manner. These results illustrate the relationship between the stress distribution and all of the design engineering characteristics used in this study. Using the three-dimensional finite elements technique and Maximum Principle Stress Failure Criteria, the results of both models were as shown in Figs. 8 and 9. It is deduced from Fig. 8, which represents the distribution of stresses in the used model that the stresses are concentrated in region 1, while the homogeneity of the stress distribution is observed in the proposed model as shown in Fig. 9.

To determine the value of the decline, two points were adopted in each critical area. The first point is at the internal bottom surface while the second point is at the outer top surface. This is due to the fact that the induced stresses at the each point is considered a field, which expresses the gradient value of the induced stresses on the entire thickness, which is 3 mm in the used model and 6 mm in the proposed model.

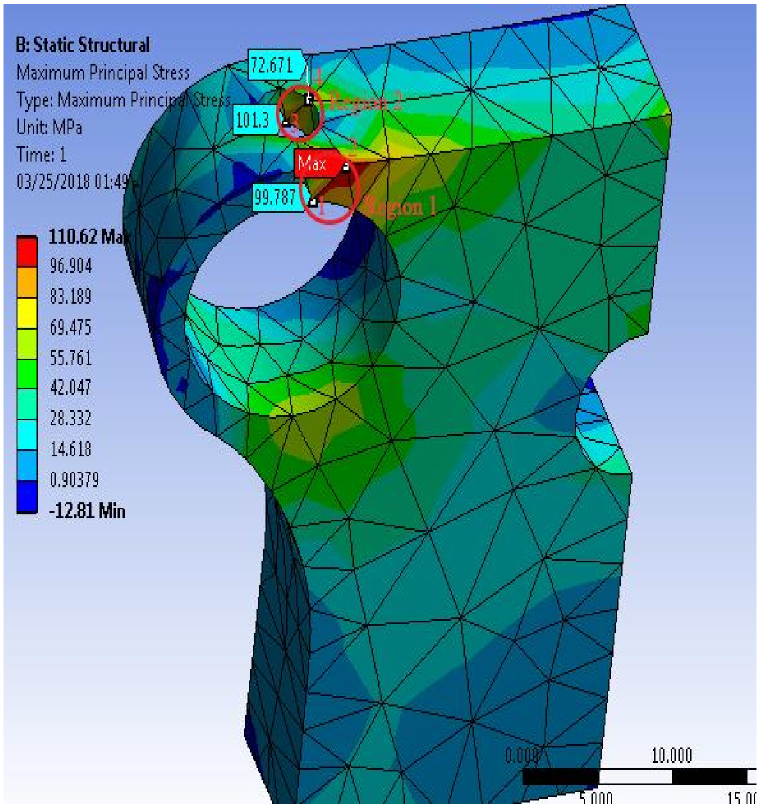

Fig. 8. Stress distribution in the model currently used

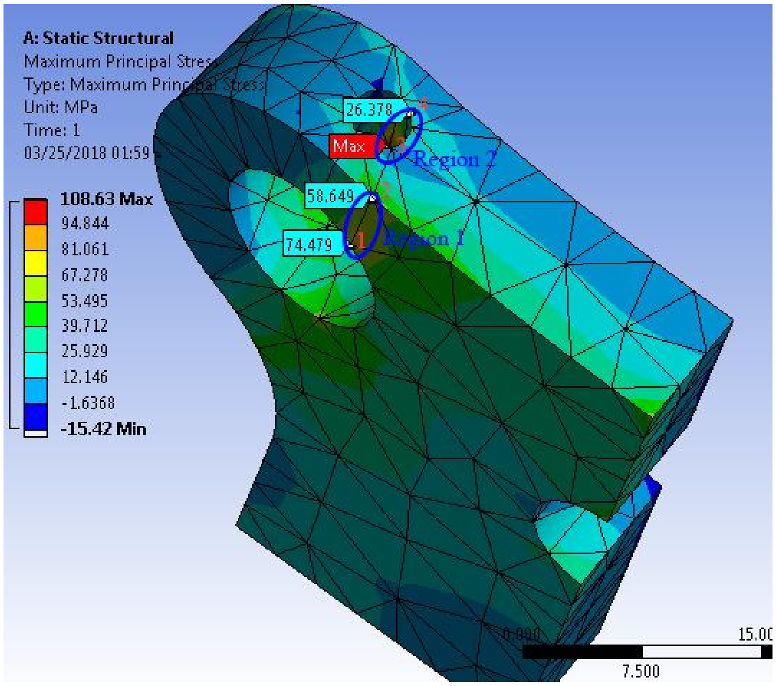

Fig. 9. Stress distribution in the proposed model

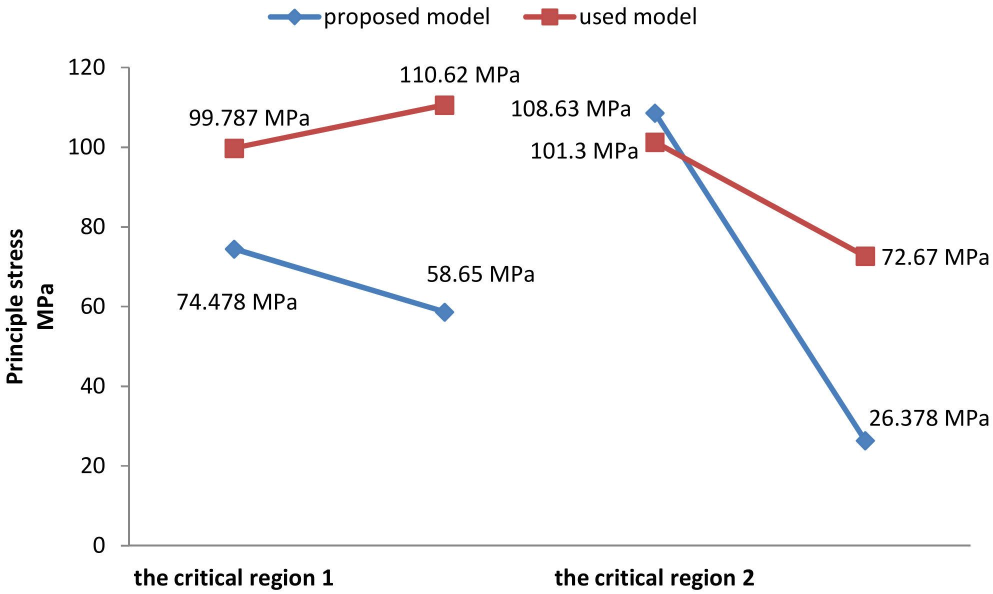

Fig. 10. The induced principle stresses in critical points for used and proposed models

The two Figs. 8 and 9 show the locations of adopted points in both models with their stresses' values. Where in region 1, points (1, 2) are taken in the current model, and points (1', 2') are taken in the proposed model. In region 2, points (3, 4) are taken in the used model, and points (3', 4') are taken in the proposed model. The difference between stresses' values in critical points in each of the studied designs was clarified as shown in Fig. 10.

In region (1), the stresses are concentrated in point 1 in the currently used model at the internal surface with 99.78 MPa, and they increase outward to a value of 110.62 MPa at point 2. While induced stresses at the same point (1) in the proposed model are reduced by 25.3 MPa to the value of 74.47 MPa, and are reduced outward in region 1 to reach 58.65 MPa. It is noted that there is a decline by 51.97 MPa in the value of stresses' concentration in point (2) from 110.62 MPa to 58.65 MPa.

In region 2, stresses are induced at 101.3 MPa in the used model at point (3). They decrease outward to the value 72.67 MPa at point (4). While the induced stresses are increased to 108.63 MPa at point (3), and decreased to 26.37 MPa at point (4). Thus, the stresses at a single point, which is point (3), are increased by 7.33 MPa, with a decrease of 46.29 MPa at point (4) in the proposed model.

We conclude that the proposed model was able to provide a decrease in the values of induced stresses in critical points (1, 2 and 4) in the used model to become safe points. Taking into consideration that there is a small increase in critical point (3) by 7.33 MPa. These results can be explained by the fact that increasing the external thickness of the joint by a double in the proposed model to the value of 6 mm, could provide a homogenous distribution for the induced principle stresses, which contributed to reducing the critical values of these stresses compared to the induced stresses in the currently used model. Increasing the external thickness of the joint plays an important role in reducing stresses, leading to an increase in the service age of plate conveyor's chain.

Although there is no similar study of the effect the outer thickness of the aluminum alloy chain has on its mechanical behavior. However, researcher Haris et al. [8], in his study of the strain element of the low-carbon steel conveyor chain, pointed out that the maximum stresses are concentrated in the outer region of the chain segment. The researches Kadam and Deshpand [9] also mentioned the same thing in their study of the chain conveyor manufactured from composite materials, which is consistent with the results obtained in this study.

4. CONCLUSION

Increasing the joint's outer thickness by double in the proposed model to the value of 6mm could provide a homogenous distribution of the induced principle stresses, which contributed to reducing the critical values of these stresses compared to the induced stresses in the currently used model. The proposed model could provide a decrease in the induced stresses' values in critical points (1, 2 and 4) for the used model to become safe points. Taking into account that there is a small increase by 7.33 MPa at point 3. Thus, increasing the joint's outer thickness has played an important role in increasing the service age of the chain plate conveyor.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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