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Durability of Thermoplastic Polyurethane Round Belt Joint with Variations in Heating Methods and Cutting Shapes

Achmad Sabilarrosyad Prawiro Kusumo, Anggit Murdani*

Department of Mechanical Engineering, Politeknik Negeri Malang, Malang, 65144, Indonesia
**Corresponding author: anggitm@polinema.ac.id*

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ABSTRACT

Thermoplastic polyurethane round belts are widely used for conveyors in various industries, particularly in the food and beverage industry, due to their flexible and abrasion-resistant characteristics. These belts are also popular in manufacturing industries because of their ease of joint. However, a common issue arises when the conveyor belt breaks during the production process. This problem can be attributed to the lack of parameters in the belt joining process at companies. Operators do not have a standard parameter for the joining process. When there is an improper joining operation of an operator, the conveyor belt could fail earlier than the expected operation time. Therefore, the conveyor belt failure results in the loss of production time. This downtime can reach up to 15 minutes, i.e. the time required for the belt joining process. Previous studies have identified temperature and heating time as factors that influence the strength of the joint, especially when using a heating plate. Therefore, this research aims to determine the optimal parameters by varying the temperature and length of heating time in the joining process. Additionally, the research explored the impact of different cutting forms on the durability of the round belt joint. The results of this study indicate that the optimal temperature and heating time combination is 100°C for 3 seconds, resulting in a joint strength of 25,274 MPa. Furthermore, the triangular joint shape proved to be the most durable, with a record of 10,021 cycles.

Keywords: *Drive belt, hot plate joint, polyurethane, round belt, thermoplastic*

I. Introduction

A conveyor is a mechanical system that moves products from one place to another [1]. Conveyors are commonly used in the manufacturing industry for transporting large and durable products [2]. They are often preferred over heavy transportation options like trucks and transport cars due to their economic value. Various types of conveyors have been developed. One popular type used in the manufacturing industry is the round belt conveyor [3]. However, this type of conveyor is prone to breaking during production due to several factors. One main factor is the absence of joint parameters used to guide operators during the joining process. Additionally, joints are often made manually without joint tools, leading to tilted or off-axis joint that easily separate.

In a manufacturing industry, when an operator error occured during the joining process, it can cause a machine to stop, resulting in a loss of production. This downtime can last up to 15 minutes during the belt-joining process. One method for joining round belt thermoplastic polyurethane is using a hot plate. Hot plate joining is a common technique in the manufacturing industry for joining certain thermoplastic components in mass

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production. The joint process using a hot plate consists of five phases: belt surface alignment, proper heating, hot plate removal, joining the belt ends, and joint cooling [4]. The heating phase is particularly important, as the temperature and length of heating time greatly impact the strength of the joint [5]. Hot plate welding can join all thermoplastics and thermoplastic elastomers with melting temperature ranges below their decomposition temperatures [4], [6]. Polymer thermoplastics are attractive materials due to their special physical properties, such as lightweight, better thermal insulation, flexibility, and good fatigue resistance [7], [8]. Durability on a conveyor belt refers to the service life of the object [9]. In the case of a belt conveyor, the durability of the joint refers to the strength of the joint under tensile force until it breaks [10]. When applied to a conveyor, durability can be understood as the time the belt can be used before it becomes damaged or broken [11]. In this study, the parameters of the joining process were varied, i.e. temperature and heating time, to find the best parameters. Then, the best-joining parameters are used to join the round belt in various shapes. Finally, the round belt is tested with the durability testing machine.

II. Material and Methods

In this study, an experimental method was used, which involved conducting two stages of experiments, as shown in Figure 1. The first stage aimed at determining the optimal parameters for the belt joining process by varying the temperature and heating time. In the second stage, the durability of the joint was tested by applying the best joining parameters and varying the shape of the joint.

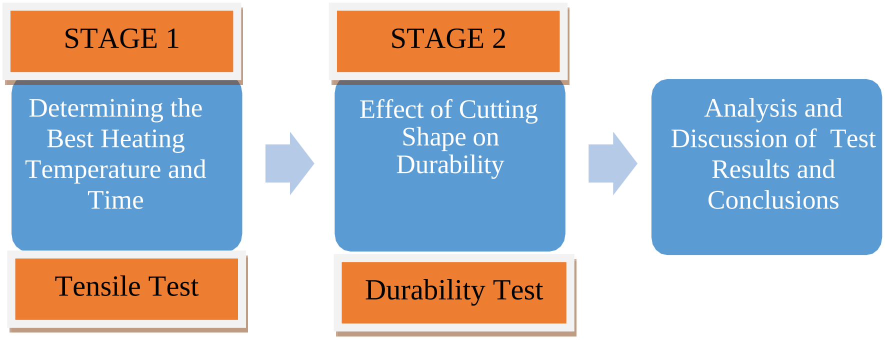


Fig. 1. The stage of the research

In the first stage, specimen preparation involves joining the belt according to the dimensions shown in Figure 2. During this process, the temperature is varied at 90°C, 100°C, and 110°C, and the heating time is varied at 3, 5, and 7 seconds. A special tool was designed and manufactured for joining round belts with a diameter of 8 mm. It is used to ensure the axes of the joint are properly aligned. After the specimens are prepared, a tensile test is conducted on each one.

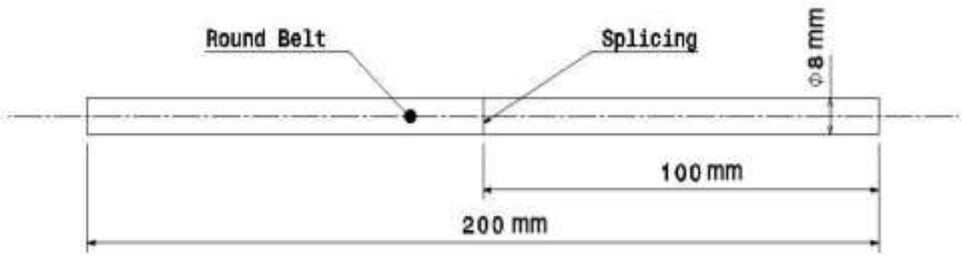


Fig. 2. Illustration of specimen dimensions

1. Joint Strength Testing

Figure 3 represents a specimen that is ready for tensile testing. The tensile testing process was carried out using a Tarno grocky tensile testing machine. The testing method is essentially the same as the standard tensile testing, where the workpiece is placed between the upper and lower grips and pulled until the material breaks. The velocity on this tensile test was 5 mm/m according to ASTM D638. However, in this testing process, a load cell sensor is added to the tensile testing machine and connected to a computer to obtain more detailed graphical results. The optimal parameters of the joint are obtained from the tensile test, and these parameters were applied to the durability test of the joint. The material of the specimens used in this study is a round belt with a diameter of 8 mm, composed of thermoplastic polyurethane (TPU), specifically type TPU-66A. The round belt is orange in color and has a smooth surface by Ammeeraal Beltech.

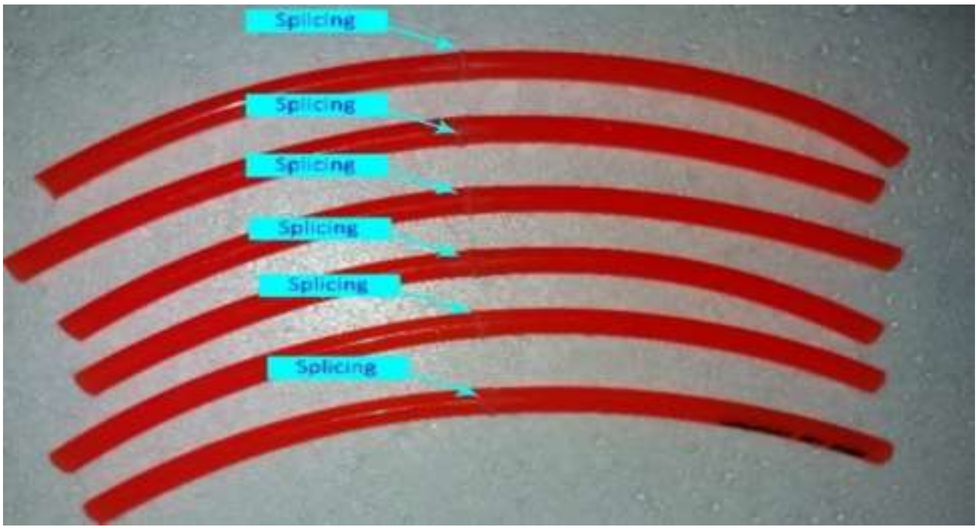


Fig. 3. Specimens round belt tensile test

2. Durability Testing of Belt joints

Durability testing is conducted by applying the optimal joint parameters determined from the tensile testing. The shape of the belt joint is varied. This research explores three variations of the joint shape, i.e. flat, triangular, and zigzag. These variations in joint shape are illustrated in Figure 4.

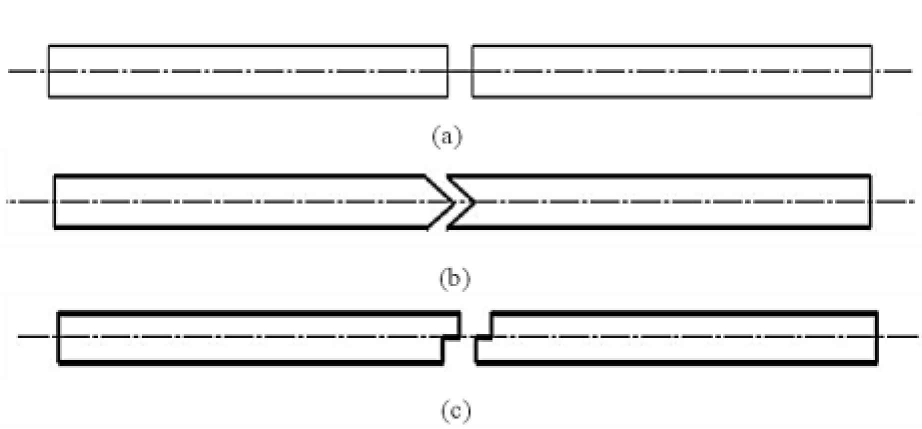


Fig. 4. Shape variation of joint; (a) Flat Joint; (b) Triangular Joint; (c) Zigzag Joint

Before conducting a durability test of the belt joint, it was simulated that the shape of the joint cut had an impact on the tensile strength value. This was verified by implementing a CATIA simulation for a tensile test. CATIA V5 R20 refers to a specific version of CATIA V5, a CAD (Computer-Aided Design) software developed by Dassault Systèmes. In this durability test, a special equipment is used to assess the durability. The test represented the operation conditions in the factory. The specimens were tested with predetermined joint shapes and attached to the roller conveyor. The testing load and speed were determined according to factory operational parameters. The testing load was 3.5 kg and the testing speed was 500rpm. To obtain accurate results, conveyors equipped with sensors are employed to keep track of the number of cycles completed before the belt eventually failed (see Figure 5). The conveyor consisted of several components that were used for durability testing. Firstly, A, a digital scale, ensured that the applied force remained consistent for every attempt. Secondly, B, a roller conveyor, served as a track to prevent the belt from dislodging while rotating. Next, C, a TPU round belt, was employed as the test specimen for the durability test. Moving on to D, a counter equipped with a sensor, detected and calculated the number of belt revolutions (cycles) throughout the test process. Lastly, E, a drive motor, was responsible for turning the belt during the test. In this study, a cycle referred to the distance traveled by the belt from point A back to point A. An overview of the cycle can be found in Figure 6.

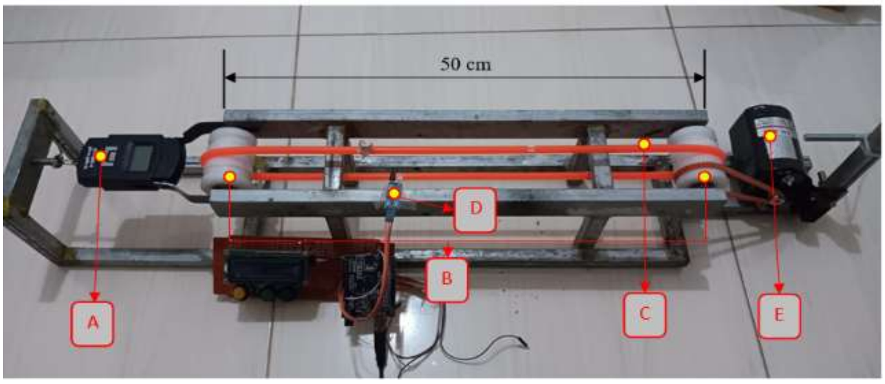


Fig. 5. Durability testing equipment

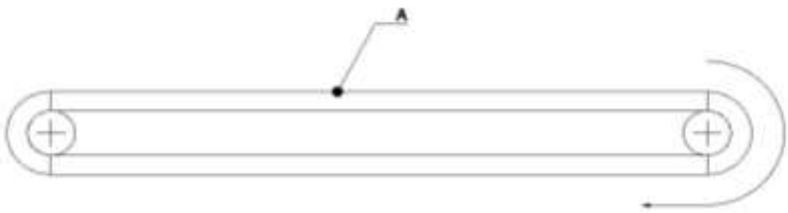
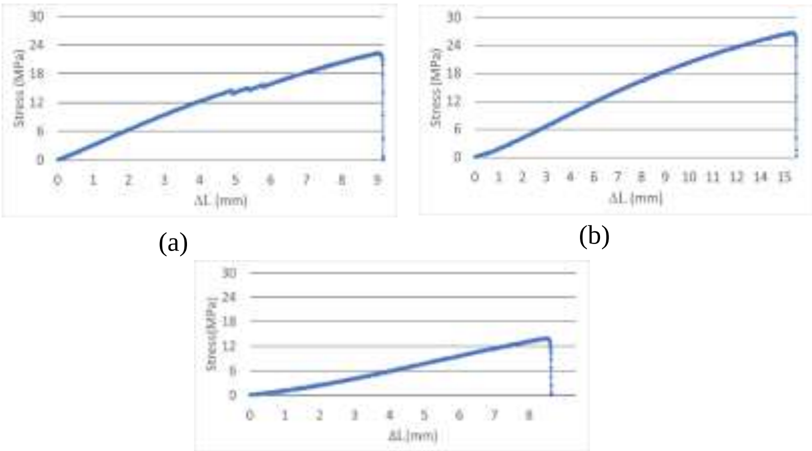


Fig. 6. Cycle Illustration in Durability Testing

III. Results and Discussions

1. *Joint Strength Test Results*

In joint strength testing, specimens are joined by varying the parameters of the joining process. The varied parameters were temperature and heating time. Figure 7 depicts the results of tensile tests on the specimens. Figure 7(a) illustrates the tensile testing of specimens at a temperature of 90°C and a heating time of 3 seconds. The graph shows a slight initial decrease followed by an increase (indicated by an arrow). This decrease indicates the occurrence of a crack in the joint during the tensile testing process. The crack occurred at a stress value of 14.91 MPa on the graph. The highest average of tensile strength reached was 22.72 MPa. Figure 7(b) presents the graph of tensile testing of specimens using a temperature of 100°C and a heating time of 3 seconds. Figure 7(b) is different from Figure 7(a) in that it exhibits a decrease and subsequent increase upon crack occurrence. In Figure 7(b), the crack occurs smoothly and consistently before ultimately breaking at a maximum value of 26.80 MPa. Lastly, Figure 7(c) displays a graph with a variable temperature of 110°C and a heating time of 7 seconds. The graph demonstrates a relatively gradual slope during the specimen-pulling process. In this graph with these variables, the crack before breaking is insignificant, and the graph tends to remain constant. The maximum stress value for this variable is 13.974 MPa. From Figure 7, it can be observed that as the temperature increases, the highest tensile strength decreases [12].



(a) (b) (c)

Fig. 7. Tensile testing behavior; (a) temp: 90 °C; time: 3s; (b) temp: 100 °C; time: 3s; (c) temp: 110 °C; time: 7s

Based on the tensile test results displayed in Figure 8, the highest tensile strength was recorded at 26 MPa when the temperature parameter was set at 100°C and the heating time 3 seconds. In contrast, when the temperature parameter was increased to 110°C, a relatively low tensile strength value was observed for the belt joint. This can be attributed to excessive heating at the belt's end, resulting in damage to the microstructure and consequently reducing the strength of the joint [13], [14].

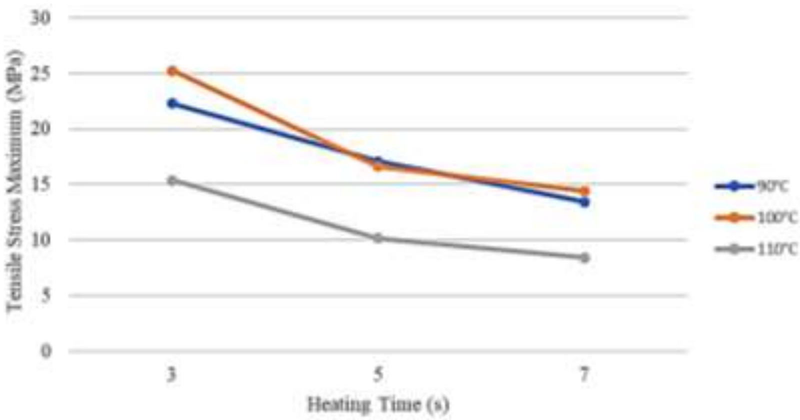


Fig. 8. Maximum tensile stress

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2. *Joint Durability Test Results*

The durability test was conducted using the most stringent parameters in the joint strength assessment, wherein a temperature of 100°C and a heating time of 3 seconds were employed. Additionally, the cutting shape of the belt joint was varied to assess its impact on the test results.

Effect of Cutting Shape Variation on Joint Strength

To examine the impact of variations in cutting shape on joint strength, Catia V5 R20 was employed to compare different types of cutting shapes. In this simulation, each type of joint was subjected to a force of 100 N, with the young modulus of the material at 72 MPa. Figure 9 depicts the wireframe view from the simulation. For the flat joint, the surface area of the joint measured 50.24 mm^2. The simulation revealed a maximum stress value of 2.83 MPa, along with a material elongation of 7.86 mm.

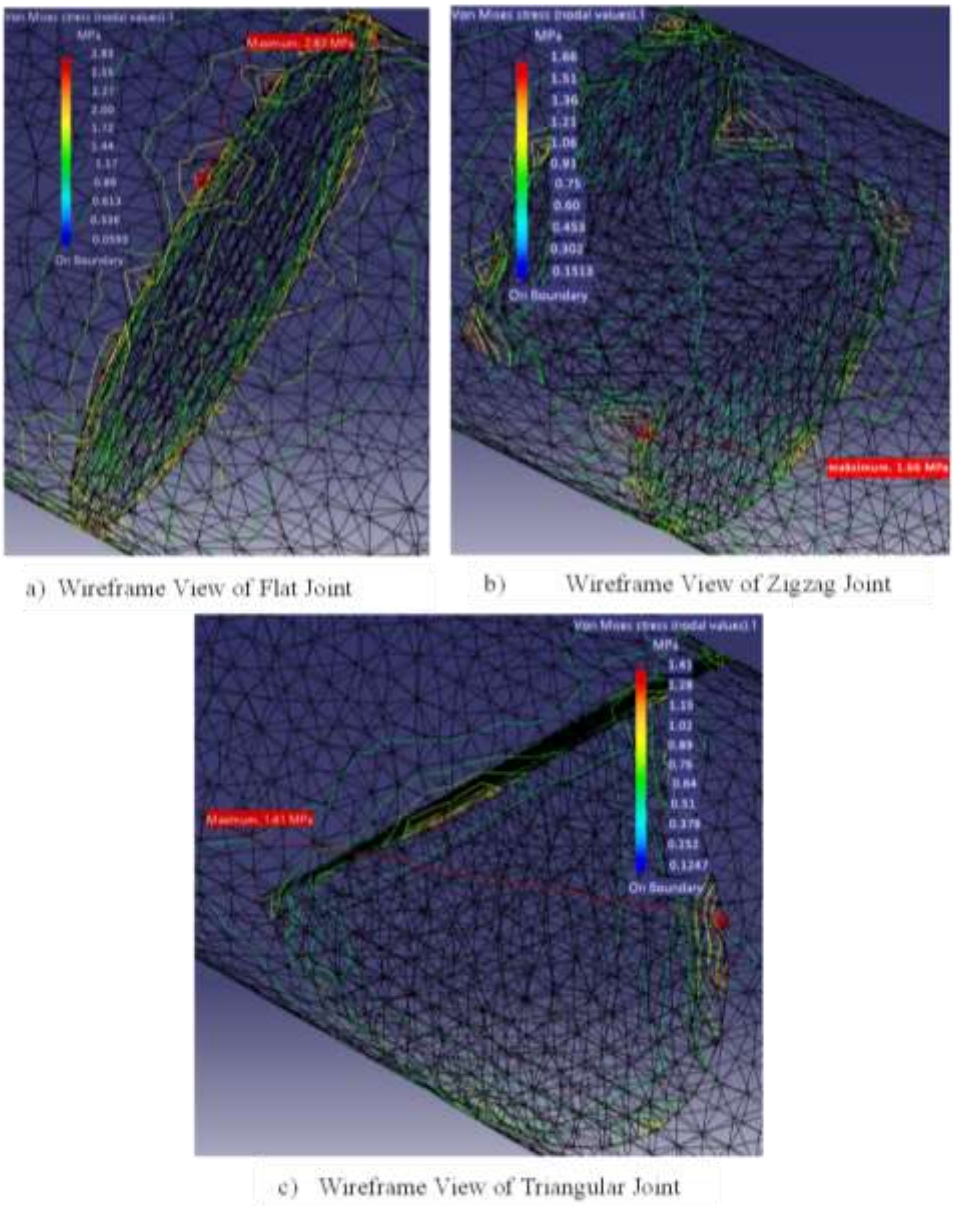


Fig. 9. Wireframe of simulation: (a) Wireframe view of flat joint, (b) Wireframe view of zigzag joint, (c) Wireframe view of triangular joint

Figure 9(a) displays the tension distribution during the initial stage of the pulling process. The picture presents the condition of the material after the simulation, with the scattered yellow color indicating the stress experienced by the test material and the red color representing the location of the highest stress during the drawing process. Moving on to the zigzag joint, it is the second variation examined in this research. For the zigzag joint, the surface area of the joint measured 74.266 mm^2. Catia was utilized to simulate the tensile strength of the material in this case. Figure 9(b) shows that the highest stress is concentrated in the corner, as indicated by the red ball. The maximum stress value in the tensile test simulation with zigzag joint was 1.66 MPa, which is lower than the highest stress value achieved by a flat joint. The Catia simulation demonstrated an increase in the length of the zigzag joint from the initial 200 mm to 204.61 mm. Finally, the triangular joint represents the third cutting variation after the zigzag joint. The simulation for this variation was conducted under the same conditions as the previous variations, using a force of 100 N. For the triangular joint, the surface area of the joint measured 82.57 mm^2. Figure 9(c) illustrates the stress distribution in the material during the drawing process. In this simulation, the highest stress recorded was 1.41 MPa, which is relatively smaller than the stress observed in the zigzag joint (1.66 MPa). In this triangular joint simulation, there has been an increase in the length of the material from 200 mm to 203.92 mm.

Based on the simulation, it is evident that there exists a variation in the highest stress value among different types of joint cutting, all subjected to the same force of 100 N. This discrepancy is attributed to the differing surface areas in each type of joint cutting. The surface area variance in cutting significantly impacts the tensile strength of the joint. As the joint surface widens, an increased number of joint ties are formed, resulting in a stronger joint [15].

Effect of Cutting Shape Variation on Durability

The durability testing process is carried out with three experiments. In each variable, the cutting form is flat, zigzag, and triangular. The results of the experiment are shown in Figure 10. In 3 times experiments, the triangular joint always got the highest result, reaching 10,000 cycles in each experiment, while the flat and zigzag joints had less than 10,000 cycles; this is because the cross-sectional area of the triangular piece is wider when compared to the flat and zigzag joint. The cross-sectional area affects the durability of the belt joint [15].

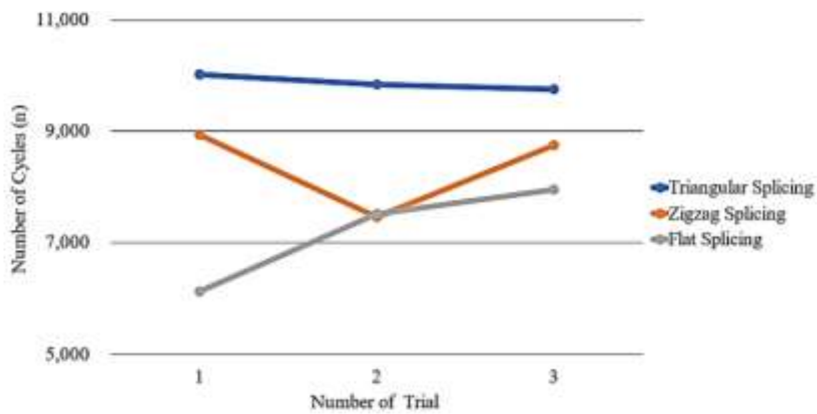
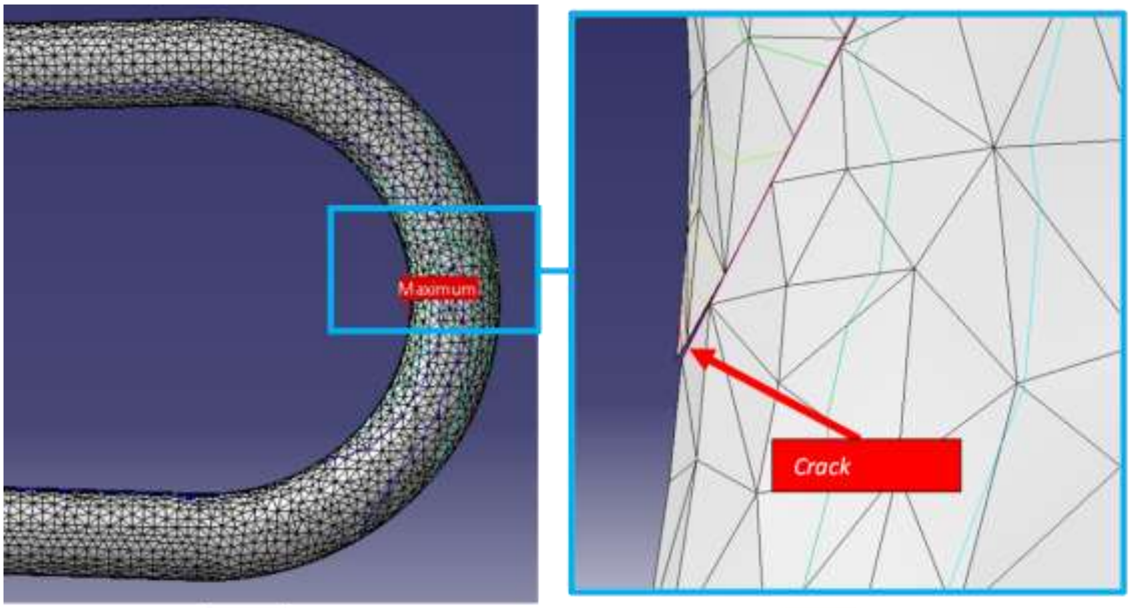


Fig. 10. Joint durability

Furthermore, the Catia application was utilized to simulate the joint condition when the belt underwent tension during rotation.

a. Specimen or Triangular

Figure 11(a) depicts a simulation conducted using the Catia application on a triangular piece. The highest stress is observed on the inner side of the belt, specifically in the region where it intersects with the pulley.



(a) (b)

Fig. 11. Condition of the triangular joint belt during rotation simulation: (a) Location of maximum stress on the triangular joint belt, (b) Crack location on the triangular joint belt

Upon closer examination of the joint area in Figure 11(b), a displacement is evident in the joint or commonly referred to as a crack in the joint. The presence of a gap at the joint represents the crack in the Catia simulation. This is illustrated in Figure 11(b), which is a magnified view of the joint area in Figure 11(a). The purple line in the figure indicates the position of the joint on the belt, while the crack itself is located at the inner end of the joint.

b. Cut B or zigzag

Figure 12 displays the outcome obtained from simulating a zigzag cutting shape. Within Figure 12(a), the position of the workpiece's highest stress point is visible alongside the location of the belt's highest stress point. Furthermore, Figure 12(a) illustrates the presence of a crack precisely at the joint point. To better understand the crack's characteristics, researchers magnified the image within the vicinity of the crack. Significantly, Figure 12(b) highlights the existence of a crack at the joint, indicated by a distance.

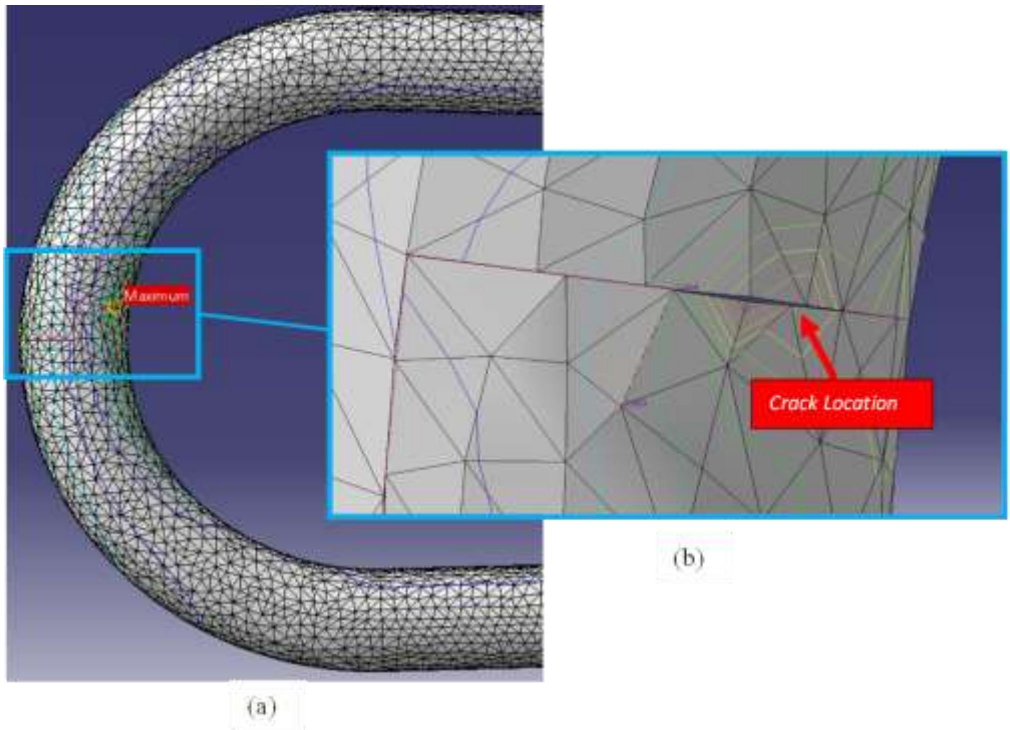


Fig. 12. Condition of the Zigzag Joint Belt during Rotation Simulation: (a) Location of Maximum Stress on the Zigzag Joint Belt, (b) Crack location on the Zigzag Joint Belt

3. *Discussion*

The tensile test in Figure 8 shows that the optimal parameters for this joining process are a temperature of 100°C with a heating time of 3 seconds. This demonstrates that temperature and heating time are influential factors in determining the strength of the belt joint [5], [16]. Furthermore, there are variations in the tensile strength values for each specimen. This discrepancy can be attributed to the microstructural condition of the material during the heating process, which also affects the formation of joint bonds [13], [17]. Unfortunately, this study does not delve into the microstructural condition of the material, thus preventing an accurate assessment of each specimen's condition. Therefore, further research is necessary to address this issue.

To assess the impact of joint surface area on the tensile strength value of the joint, the researchers conducted a simulation, as depicted in Figure 9. The disparity in stress values confirms the influence of the joint surface area on the tensile strength value of the joint [15]. Augmenting the joint strength value consequently affects the joint's durability, as durability in the context of a belt conveyor refers to the joint ability to withstand tensile forces until failure occurs [10]. Based on the test results in Figure 10, the triangular joint consistently achieved the highest result, enduring 10,000 cycles in each experiment, while the flat and zigzag joints fell short of 10,000 cycles. This discrepancy can be attributed to the wider cross-sectional area of the triangular joint compared to the flat and zigzag joints. Additionally, there are fluctuations in the cycle values achieved by each specimen, potentially due to variations in the microstructural conditions of the joints. Heat treatment has the potential to alter the microstructural properties of thermoplastic polyurethane, thereby influencing the strength of the joint [6], [18]. Consequently, further research is still necessary to investigate the microstructural conditions of the joints. As this study does not address the microstructural condition of the joint, a simulation was conducted to examine the joint's condition during durability testing, as illustrated in Figure 11 and Figure 12. The simulation process revealed the highest stress at the belt joint. At this maximum tension, a gap between the two belt surfaces was observed, indicating the presence of a crack and signaling an impending belt failure [19], [20]. The two simulations possess a shared characteristic, specifically the occurrence of cracks in the vicinity of the pulley. This observation aligns with prior research, which suggested that the highest stress on the belt is concentrated in the pulley area due to the forced deformation of the belt [21], [22].

IV. Conclusions

The present study investigates the influence of variable temperature and heating time on the joining process of Thermoplastic Polyurethane round belts. Through experimentation, the optimal parameters have been determined to be a temperature of 100°C and a heating time of 3 seconds. Under these conditions, a joint strength of 25.274 MPa was achieved. Additionally, the durability of belt joints was assessed by considering different cutting shapes. Notably, the triangular cut shape exhibited the highest effectiveness, with the belt's durability reaching 10,021 cycles. Unfortunately, this study does not delve into the microstructural condition of the material, thus preventing an accurate assessment of each specimen's condition. Therefore, further research is necessary to address this issue.

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