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# ANALYSIS OF THE INFLUENCE OF WEAR CRACK OF CHAIN DRIVE ON STRESS IN ITS ELEMENTS

# ANALIZA WPŁYWU ZUŻYCIOWEGO PĘKANIA ŁAŃCUCHA NAPĘDOWEGO NA WYTĘŻENIE JEGO ELEMENTÓW

**Key words:** chain transmission, wear, elongation, stress, finite element method.

**Abstract:** Pin joints of chain transmissions are areas of stress concentration, which can lead to the formation of cracks in the links. This process often contributes to a critical weakening of the cross-section in the lugs of these links, which results in its damage and may lead to the failure of the entire drive. The article analyses the influence of exemplary wear damages of chain transmission elements on the magnitude of stress concentration. The impact of the load, crack size, and its location on the level of stress increase was assessed. The location of cracks in the lugs of chain plates transmission links which lead to the most significant increase in stress level was identified.

**Słowa kluczowe:** przekładania łańcuchowa, zużycie, wydłużenie, naprężenie, metoda elementów skończonych.

**Streszczenie:** Połączenia sworzniowe przekładni łańcuchowych są miejscem koncentracji naprężeń, które mogą prowadzić do powstawania pęknięć w ogniwach. Proces ten często przyczynia się do krytycznego osłabienia przekroju w uchach tych ogniw, co skutkuje jego zniszczeniem i może prowadzić do niesprawności całego napędu. W artykule przeanalizowano wpływ przykładowych uszkodzeń zużyciowych elementów przekładni łańcuchowych na wielkość spiętrzenia naprężeń. Dokonano oceny wpływu wielkości obciążenia, wielkości pęknięcia oraz jego lokalizacji na poziom przyrostu naprężeń. Zidentyfikowano położenie pęknięć uch płytek gąsienicowych przekładni łańcuchowych, które prowadzą do największego spiętrzenia wytężenia.

## INTRODUCTION

Chain transmissions are commonly used in many areas, including production lines, transportation, agriculture or mechanical driving units **[L. 1–3]**. Joints of those mechanisms, including pins and bushes, play a key role in terms of the durability of the transmissions as there the wear rate is the highest **[L. 3, 4]**. Most research is dedicated to studying pins' work, while less focus is given to bushes **[L. 5]**. This issue is of broader importance as similar problems can be observed in caterpillar chain components which work on the same basis as classic chain drives **[L. 6, 7]**. Accelerated wear of their joints in disadvantageous working conditions is unavoidable, but it can be lowered thanks to several measures. Among those solutions application of bushings with lower hardness inside the joints can be pointed out. Their resilience to wear is lower than in links, so the deterioration of the technical condition of the latter parts runs slower. That is beneficial for the maintenance costs of the entire assembly.

Tribological issues play an essential role in the reliable work of chain transmission, and appropriate lubrication is a crucial problem. However, lubricants' influence on friction coefficient can vary depending on the parameters of the outer layers of particular elements. The coefficient of friction in chain transmissions depends mainly

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on the lubricant only when mating elements have high roughness. In the case of a small value of this parameter, the influence of lubricant is negligible **[L. 2]**. However, regardless of these observations, applying any lubricant is better for the operation of chain drives than working under dry friction conditions **[L. 8]**.

Vibrations, among other important factors influencing the chain transmission's durability, can be pointed out. It is particularly observed in the case of high values of loadings. Excessive dynamics can also affect the chain's tension **[L. 9]**. In **[L. 10]**, a study was carried out by evaluating loadings in driving units of scraper conveyors, machines used in demanding mining conditions. Oscillations, variability and even eccentricity of forces acting on chain systems accelerate wear processes. Additionally, speed fluctuations also influence the dynamics of the chain assembly and its durability **[L. 11]**. The slack side is particularly endangered to the occurrence of vibrations **[L. 3]**.

It should be highlighted that one of the main problems during the operation of those systems is a change of dimensions of chain elements resulting from wear. The origin of this wear is located within pins and bushings of kinematic pairs, where constant movements occur **[L. 12]**. The elongation of chains negatively influences the work of those transmissions. For this reason, many research works are focused on calculating the course of this phenomenon or testing it and improving the technical conditions of chain drives. Both experiments on real objects and computer simulations have been done **[L. 1, 2, 12–20]**.

The run of the chain elongation process depends on several factors, among which overloading and wear of kinematic joints can be distinguished as crucial **[L. 19]**. It was observed that the wear of chain elements, for instance, the abrasive ones, decreases the pitch of the sprockets and increases the chain's pitch. The consequences of such a phenomenon are immense as the geometry of interaction within the chain mechanism changes. As a result, the trajectory of the chain movement relative to the sprockets varies. Consequently, different areas of mating surfaces are in contact with and distribution of loading changes **[L. 19]**. In some cases, when the change of interaction is excessive, further operation of the chain mechanism can even be impossible. Hence, keeping the chain elongation under control is very significant, and the maximum acceptable increase of chain pitch is 3% in the case of low-speed drives and only 0,5% for timing drives **[L. 2, 21]**.

Additionally, it was observed that the crucial stage of chain movement in contact with the teeth of sprockets, as more than two-thirds of the cases of wear and resulting elongation of chain pitch, occurs in that period of operation **[L. 13]**.

One should consider that failures can still occur even when the strength parameters of chain assemblies, their chemical composition and elongation fulfil the design recommendations. Manufacturing processes, including welding and heat treatment, can still lead to failure propagation, introducing disadvantageous features like embrittlement or segregation of chemical components. One of the studies showing the significance of this issue can be found in **[L. 22]**.

## PURPOSE OF ANALYSES AND RESEARCH METHOD

The work aimed to assess the impact of the degradation of chain drive components on the change in the level of von Mises stress in the links. A model of the transmission's tight side was developed, which consisted of 3 links, two pairs of chain plates connecting them, and pins placed in the holes in these elements.

According to **[L. 23]**, various states can be distinguished during the operation of a chain transmission:

- press-fitting state, which corresponds to the slack side of the chain,
- tensile state, which corresponds to the tight side of the chain,
- sprocket-engaging state, which corresponds to the mating between the driving sprocket and the chain,
- the scope of the analyses in this article covered the tensile state.

The model and the boundary conditions are shown in **Figure 1**. Based on literature recommendations, the choice to simulate the operation of only part of the drive was made, according to which modelling and testing only part of the transmission is one of the two acceptable strategies **[L. 3, 21]**. The second one requires modelling the entire chain drive, which extends the analysis time; therefore, this solution was not chosen.

The wear of the transmission elements was simulated by introducing sample cracks into a chain plate. The impact of the location and size of these cracks was analysed in specific places of their appearance, according to **[L. 23]**, i.e. propagating around the pin hole. There are four locations around the circumference of the front pin hole in the chain pin connecting plate selected for this study: above, below, in front of and behind this hole (**Fig. 2**).

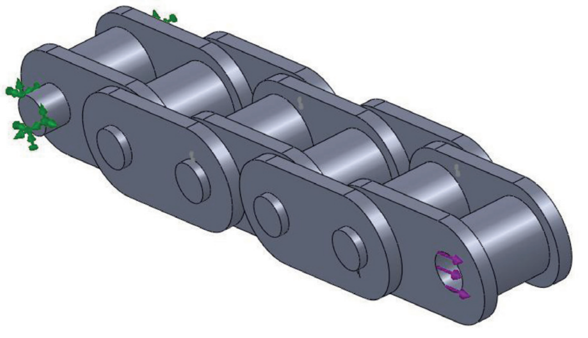

**Fig. 1. Model of the chain assembly. Boundary conditions are marked: the rear pin is fixed (green), which corresponds to its sitting in driven gear, while the front link is loaded with a force (purple) resulting from a driving torque**

Rys. 1. Model fragmentu łańcucha z oznaczeniem warunków brzegowych: tylny sworzeń zablokowany, symulując jego osadzenie we wrębach koła łańcuchowego biernego, do przedniego ogniwa przyłożono siłę wynikającą z działania momentu obrotowego

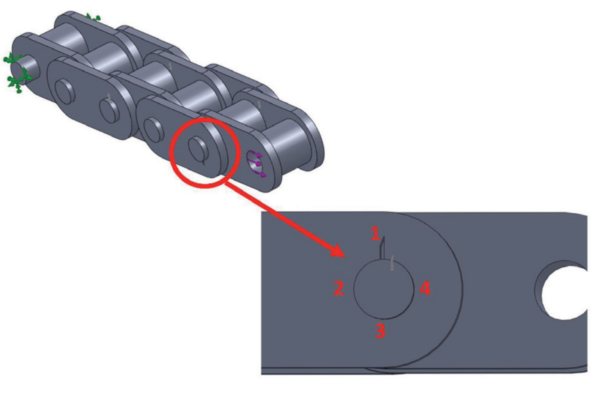


**Fig. 2. Model of the chain assembly. Four points around the pin joint hole where a crack was introduced are marked. In the Figure, the modelled crack is in point 1**

Rys. 2. Model fragmentu łańcucha. Oznaczono 4 punkty wokół otworu podsworzniowego, w których wprowadzano uszkodzenie. Na rysunku modelowe pęknięcie znajduje się w punkcie 1

The simulations also examined the impact of different values of transmission load (5 kN and 10 kN) on the increase of the analysed level of von Mises stress (average and maximum value) in:

- entire plate,
- the outer part of the plate,
- the inner part of the plate (chain link side).

The last of the analysed factors was the size of the crack, with two sizes taken into account: the depth of the crack perpendicular to the hole axis below 1 mm (small crack) and below 2 mm (large crack). For each case, the crack was uniform throughout the plate thickness.

The finite element method was used in the analyses.

The selected geometrical and material parameters are listed in **Table 1**. The material properties were taken based on **[L. 23]**.

**Table 1. Geometrical and material data included in the analyses**

Tabela 1. Dane geometryczne i materiałowe przyjęte do analiz

| | |
|---|---|
| Chain pitch, mm | 13.1 |
| Pin diameter, mm | 4.4 |
| Inner bush diameter, mm | 11.4 |
| Bush width, mm | 1.6 |
| Pin material | X8CrCoNiMo10-6 |
| Bush material | 34CrMo4 |

## RESULTS

Typical simulation results are shown in **Figs. 3–5**. An increased level of von Mises stress was observed for all the analysed cases between the pin holes, and it was the case in both links and chain plates. It was observed regardless of the crack's location and in the chain without the introduced damage as well. It should be noted that the location of the crack had a significant impact on an increase of von Mises stress around the hole at which it occurred. Stress concentration occurred close to the crack, in particular at the bottom of the crack. It is shown in **Figures 4** and **5**, where the stress concentration occurred at the bottom of the crack either way for oppositely located cracks (in one case above the hole, in the other case below the hole).

**Tables 2–4** show a summary of the relative increase of von Mises stress within the damaged plate depending on the size and location of the crack. Maximum and average stress values were analysed. For the assumed simulation parameters, the stress increase caused by the introduction of the crack was only local, and the average stress level was negligibly small (values below 5%). However,

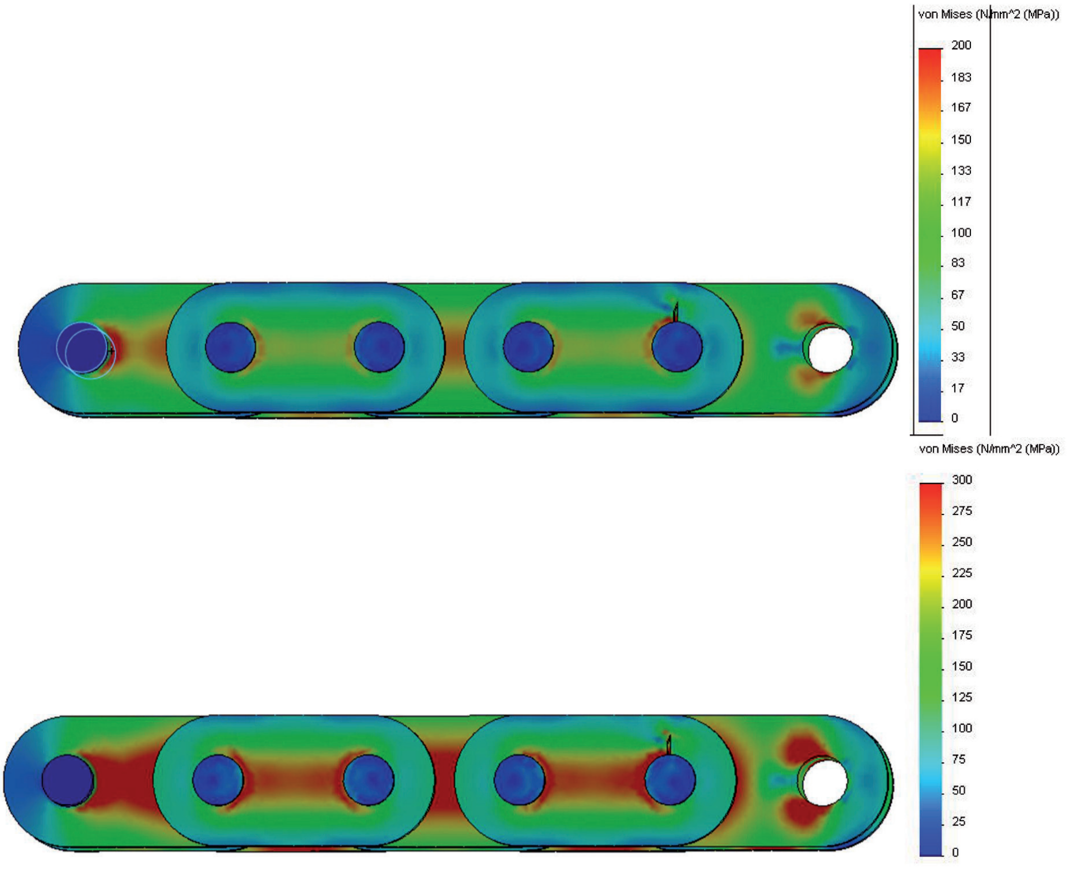


**Fig. 3. Typical von Mises stress distributions for smaller loading (5 kN, upper Figure) and higher loading (10 kN, lower Figure). Description in text**

Rys. 3. Przykładowe rozkłady naprężeń zredukowanych wg hipotezy von Misesa – Hubera przy obciążeniu mniejszym (5 kN, rysunek górny) oraz większym (10 kN, rysunek dolny). Opis w tekście

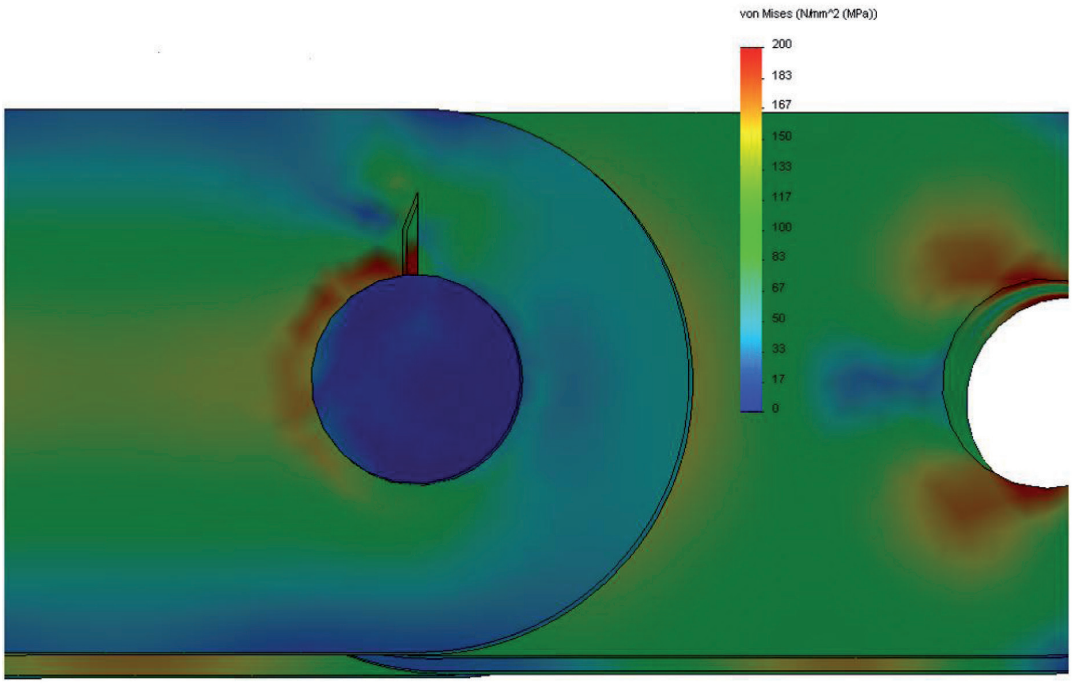


**Fig. 4. Typical von Mises stress distribution in the critical area of the analysed assembly for a case with a crack above the pin joint hole**

Rys. 4. Przykładowy rozkład naprężeń zredukowanych w najbardziej wytężonym miejscu analizowanego układu dla pęknięcia powyżej otworu podsworzniowego

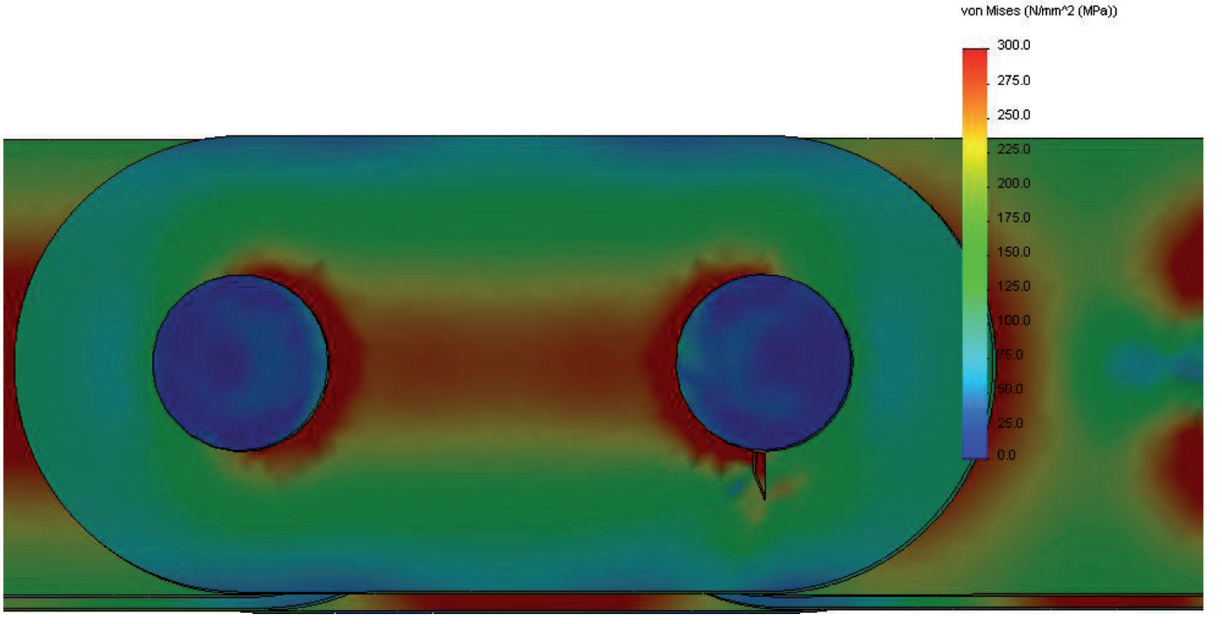


**Fig. 5. Exemplary von Mises stress distribution for a case with a crack below the pin joint hole**
Rys. 5. Przykładowy rozkład naprężeń zredukowanych dla pęknięcia poniżej otworu podsworzniowego

**Table 2. Relative increase of maximum (a) and average (b) von Mises stress for the entire plate. Comparison of influence of crack location and its position in relation to the pin joint hole**
Tabela 2. Względny przyrost maksymalnego (a) oraz średniego (b) naprężenia zredukowanego dla całej płytki. Porównanie wpływu wielkości szczeliny oraz jej położenia względem otworu podsworzniowego

| a) | Crack location against the pin joint hole podsworzniowego | | | |
|---|---|---|---|---|
| Crack size | Above | Behind | Below | In front |
| Small (< 1 mm) | negligible | ca. 35% | ca. 40% | ca. 30% |
| Large (< 2 mm) | ca. 10% | ca. 40% | ca. 20% | ca. 30% |

| b) | Crack location against the pin joint hole podsworzniowego | | | |
|---|---|---|---|---|
| Crack size | Above | Behind | Below | In front |
| Small (< 1 mm) | negligible | negligible | negligible | negligible |
| Large (< 2 mm) | negligible | negligible | negligible | negligible |

**Table 3. Relative increase of maximum (a) and average (b) von Mises stress for the outer surface of the plate. Comparison of influence of crack location and its position in relation to the pin joint hole**
Tabela 3. Względny przyrost maksymalnego (a) oraz średniego (b) naprężenia zredukowanego dla ściany zewnętrznej płytki. Porównanie wpływu wielkości szczeliny oraz jej położenia względem otworu podsworzniowego

| a) | Crack location against the pin joint hole podsworzniowego | | | |
|---|---|---|---|---|
| Crack size | Above | Behind | Below | In front |
| Small (< 1 mm) | ca. 10% | ca. 45% | ca. 55% | ca. 20% |
| Large (< 2 mm) | ca. 15% | ca. 40% | ca. 30% | ca. 20% |

| b) | Crack location against the pin joint hole podsworzniowego | | | |
|---|---|---|---|---|
| Crack size | Above | Behind | Below | In front |
| Small (< 1 mm) | negligible | negligible | negligible | negligible |
| Large (< 2 mm) | negligible | negligible | negligible | negligible |

**Table 4. Relative increase of maximum (a) and average (b) von Mises stress for the inner surface of the plate. Comparison of influence of crack location and its position in relation to the pin joint hole**

Tabela 4. Względny przyrost maksymalnego (a) oraz średniego (b) naprężenia zredukowanego dla ściany wewnętrznej płytki. Porównanie wpływu wielkości szczeliny oraz jej położenia względem otworu podsworzniowego

| a) | Crack location against the pin joint hole podsworzniowego | | | |
|---|---|---|---|---|
| Crack size | Above | Behind | Below | In front |
| Small (< 1 mm) | negligible | ca. 35% | ca. 35% | ca. 30% |
| Large (< 2 mm) | ca. 10% | ca. 40% | ca. 20% | ca. 30% |

| b) | Crack location against the pin joint hole podsworzniowego | | | |
|---|---|---|---|---|
| Crack size | Above | Behind | Below | In front |
| Small (< 1 mm) | negligible | negligible | negligible | negligible |
| Large (< 2 mm) | negligible | negligible | negligible | negligible |

the increase in maximum stress was higher, primarily in the case of cracks located at the back, bottom and front of the hole. For a crack localised:

- Above the pin hole, the relative increase in maximum stress was several per cent for the entire plate and its inner side. The occurrence of a crack above the hole increased the maximum stress level by approximately 15%.
- In front of the hole, the relative increase in maximum stress for each of the analysed areas (entire plate, outer or inner side of the plate) did not exceed 30%.
- At the back of the hole, the relative increase in maximum stress for the entire plate and its inner side was less than 40%. For the outer side, this increase exceeded 40%.
- Under the pin hole, the relative increase in maximum stress varied significantly as it depended on the crack's size. The small crack caused a relative increase in maximum stress, almost twice as big as for the large crack. It was observed only for this crack location and occurred for all analysed areas (the entire plate, outer and inner plate sides). For the entire plate and its inner side, this increase did not exceed 40% for the small crack and did not exceed 20% for the large crack. This influence was significantly higher for the outer side, where the increase in maximum stress caused by the appearance of a small crack locally exceeded 50%, and for a large crack, it was at the level of 30%.

## SUMMARY

Several observations can be formulated based on the analysis of the simulation results. They were divided into general and detailed ones.

General observations:

- The influence of the load on the analysed stress values was directly proportional.
- The effect of the crack size on the stress level depended on the location of the crack.
- For each crack location, the stress concentration occurred at its bottom. The value of this increase depended on the location of the crack.

Detailed observations:

- The increase in the average stress level caused by the crack formation was negligible in all analysed cases. The stress increase caused by the simulated damage was local and only close to the crack.
- The increase in maximum stress was the highest for a crack behind and below the pin joint hole (average difference approx. 40%, maximum difference over 50%).
- The increase in maximum stress was the smallest for the crack located in the upper part of the hole (from below 20%).
- A significant effect of the crack size was found for the crack under the hole. Small cracks increased the maximum stress more than large cracks. For the remaining damage locations, the impact of the crack size on the increase in maximum stress was negligible or minor.

To sum up, it can be concluded that a crack above the pin hole can be treated as the least dangerous because its presence leads to a lower increase in von Mises stress. The cracks in other analysed locations relative to the pin joint hole have a similar effect on the increase in maximum stress in the plate. Further research is planned to extend the analyses with material tests based on assessing the stress intensity factor, taking into account the theory of fracture mechanics.

Additionally, the contact pressure within the pin joint is not uniform in the transverse direction. The highest values of this parameter occur in the outer part of the interaction area. The reason for such a distribution is the influence of adjacent links on these connections. It translates into a higher wear rate in these areas and has been observed in other studies **[L. 21]**.

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