http://dx.doi.org/10.7494/miag.2018.1.533.81

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Corroded steel support friction joint load capacity studies as found in Piast-Ziemowit coal mine

This article presents the load capacity study results of the corroded friction joints obtained during heading relining conduction. The main goal of the study was to determine the operational characteristics of heavily corroded friction joints as well as their load capacity. An additional goal of the study was to indicate which parameter is crucial from the point of view of corroded support technical condition evaluation – friction joint load capacity or arch strength. Mine conditions in which the LP support operated were also briefly characterized in the article. The study presented in the article is of a pilot character; while the obtained results reveal a very significant influence of corrosion on the support operational safety, the studies of corroded joints will be continued in the future using a larger number of samples and various types of shackles.

Key words: *corrosion, heading support, friction joints, load capacity study*

1. INTRODUCTION

A steel frame support is the basic gallery working support utilized in Polish hard coal mines. The reasons for this are the many advantages of this type of support, including its easy adjustment to geological and mining conditions, fast manufacturing, relatively low cost, and wide array of available support size variants. Despite this, the steel frame support has one significant flaw; its load capacity changes over time together with the progressing corrosion of its frame. Thus, its durability is limited and dependent (among other things) on the aggressiveness of the environment in which it is utilized. Based on underground observations, it can be concluded that steel frame supports retain their functional quality over a period of several to dozens of years. It is obvious that specific steel support components are susceptible to aggressive environmental influence to a different extent. Frame durability is considerably higher than that of thin-walled elements, such as wire mesh lining or frame sprags. While it is possible to supplement, replace, or apply repairs to most accessories in the event of significant corrosion, it is necessary to reinforce (underpin) or replace them in the case of frames, which results in costly heading reconstruction [1]. To avoid emergencies when support load capacity falls to the level of the load it is subjected to (and results in heading stability loss risks as well as caving and rock slide risks), mining staff should periodically conduct support technical condition controls. A number of corrosion studies have been conducted thus far (including concerning mining supports) [2–6], and many methodologies have been developed, making it possible to assess the load capacity of a corroded frame based on real V-section wall thickness measurements [7–11]. Friction joint load capacity is another very significant issue [12–15] that influences the frame spacing determined during support selection [16–18], though it is omitted in the referenced corroded support assessment methodologies. This is due to the fact that, in underground conditions, it is difficult to determine or at least estimate the load capacity of friction joints in which support arch consolidation occurred as a result of crevice corrosion. This particularly concerns corroded frames, when it is difficult to determine the load capacity of a friction joint in an indirect way. To assess this load capacity, a series of bench studies were conducted on the frame friction joints obtained during heading relining conduction. An additional goal of the studies was to determine which parameter is crucial from the point of view of corroded support technical condition evaluation – friction joint load capacity or arch strength.

2. MINE ENVIRONMENT CHARACTERISTICS IN OPERATION AREA OF STUDIED FRICTION JOINTS

The mine environment changes along with characteristic factors such as hydrologic conditions, burial depth, humidity, surrounding rock virgin temperature, temperature of the machines and devices operating in a given heading, airflow, etc. Based on studies and observations, it was determined that mine water aggressiveness has the greatest influence on the corrosion process speed in the Piast-Ziemowit Ruch Ziemowit coal mine.

Four basic characteristics of mine water determine its aggressiveness:
- hydrogen ion concentration (pH),
- total hardness,
- amount of chlorides,
- amount of sulfides.

Friction joint samples for laboratory testing were obtained from East Drift 930, Level III (650m) during the relining conducted there. Basic data concerning the support has been collected in Table 1.

The support was set in 1998; therefore, it has been operational for 20 years. Breakaways of corrosion products and heavily corroded shackles were visible on the support arches. The environment in the sampling area was very aggressive. Relative air humidity in the heading was at a level of 88%. Additionally, the analyzed water was characterized by very high mineralization; it contained 149,500 mg/dm^3 of solutes and had high hardness – 1019° n. The average chloride ion concentration of 84,373 mg/dm^3 and sulfide of 3323 mg/dm^3 at a significant layer of humidity on the support surface resulted in the acceleration of the corrosion processes. Furthermore, 3466 mg/dm^3 of magnesium cations and 4280 mg/dm^3 of calcium cations had an influence on the considerable water hardness.

Taking into account the time when the support was in operation and the very high mineralization of the water condensing on the support surface (high even for mine conditions) resulting in the acceleration of the corrosion processes, the support together with the friction joints in East Drift 930 can be considered heavily corroded.

Table 1

Steel support characteristics [19]

Frame size	Section	Grade of steel	Number of shackles in joint	Shackle type	Year of setting
LP9	V29	25G2	2	K29	1998

Table 2

Physico-chemical properties of water in studied support operation area [19]

Solutes [mg/dm^3]	pH	Total hardness [°n]	Cations [mg/dm^3]		Anions [mg/dm^3]		
			Ca^{+2}	Mg^{+2}	Cl^-	SO_4^{-2}	HCO_3^-
149,500	6.5	1386	4280	3466	84,373	3323	122

3. COURSE AND RESULTS OF STUDIES

Bench tests were conducted on two LP support friction joints constructed from V29 sections, obtained during the relining of East Drift 930 at Level III in the Piast-Ziemowit Ruch Ziemowit coal mine.

Arcuate joint tests without passive pressure (passive force exerting influence on the joint) were conducted according to the load diagram presented in Figure 1 (based on standard PN-G-15026:2017-04) [20].

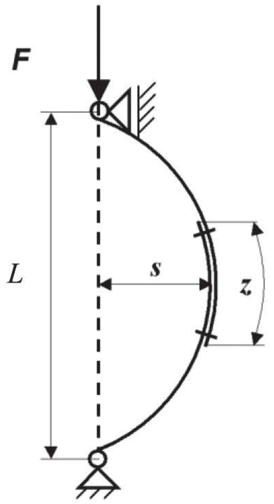

Fig. 1. Load diagram of arcuate joint subjected to force F acting in fixed support pivot axis, where L is the joint chord length, s – joint arrow length, and z – overlap length

Negative bending moment value M_g (decreasing the joint arch radius of curvature) in the joint cross-section (in the location of its arrow s) was calculated from the following formula:

$$M_g = -F \cdot s \text{ [kN·m]} \quad (1)$$

where:

F – force loading the joint during its yield [kN],

s – joint arrow length [m], calculated as the distance between the neutral axis of two V29 sections in the joint and the force F axis.

The test stand was equipped with a hydraulic actuator with a strain gauge force sensor (operating in a full-bridge configuration) with a measuring range of up to 1000 kN (Class 0.5), mounted on the piston rod and a potentiometric displacement transducer with a measuring range up to 1500 mm (Class 0.35) for joint chord length alteration ΔL measurement during its loading.

During testing, force F loading the joint and joint chord length L were measured with a sampling rate of f_p = 10 Hz, which is sufficient to determine the operational characteristics of LP support frame friction joints (as demonstrated by the many years of friction joint studies within an accredited laboratory). The sensors were connected to a DMCPLUS-type measuring amplifier with an accuracy class of 0.03. Measurement data was registered on a computer using the CATMAN program.

Before conducting the tests, the joints had an overlap of approx. 560 mm, while the joint arrows s were approx. 108 mm long (measured from the force F axis to the joint neutral axis) [12–13].

The joint ends in contact with the tensile testing machine parallel loading plates were cut in such a way so they would adhere to the machine plates. Due to the fact that section perforations were found in the joint (Fig. 2), its ends were additionally reinforced with a V29 section segment and a single shackle. This was done to prevent the occurrence of V29 section deformations in the joint (which would block its yield) and, thus, disrupt the joint course of operation. A view of the joints prepared for testing is presented in Figures 3 and 4.

Fig. 2. Section perforation in flange area

Fig. 3. Friction joint 1 prepared for testing and shackle technical condition

Fig. 4. Friction joint 2 prepared for testing and shackle technical condition

Test results in the form of $F = f(\Delta L)$ courses are presented in Figures 5 and 6.

Geometric measurements of the K29 bow shackles in friction joint 1 showed that the M27 bow bolts exhibited slight corrosion resulting in bow diameter reduction within a range of 25–26 mm (both in the lower and upper shackles). The joint overlap of $z = 560$ mm did not change (neither before nor after testing).

During Test 1, the joint loaded with a force of $F = 700$ kN at a bending moment of M_g=75.6 kNm did not yield, and no plastic deformation was found in it after the test either. Arcuate joints constructed from V29 sections connected with two K29 shackles typically tend to yield at a loading force of approx. 220 kN. The blocking of the joint was most likely the result of crevice corrosion between the arches, which resulted in the locking of the sections and shackles in the joint.

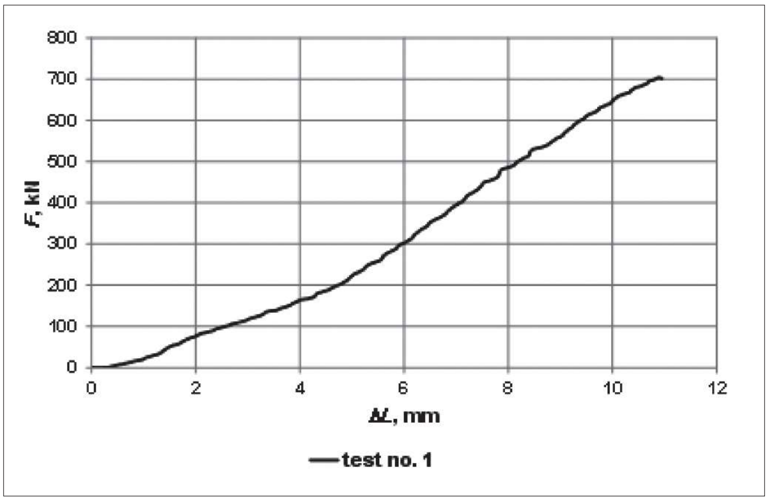

Fig. 5. Friction joint 1 characteristics

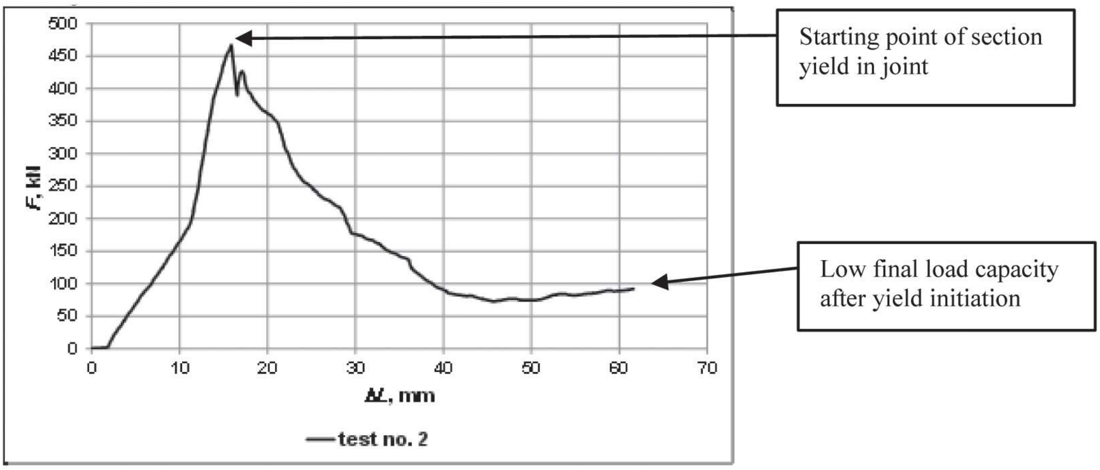

Fig. 6. Friction joint 2 characteristics

Geometric measurements of the K29 bow shackles in friction joint 2 showed that the M27 bow bolts exhibited significant corrosion resulting in bow diameter reduction within the ranges of 7–20 mm in the upper shackle and 18–23 mm in the lower shackle.

A different manner of operation was observed during Test 2. The joint loaded with a force of $F = 467$ kN and a bending moment of $M_g = 50.4$ kNm did yield (Fig. 8). The yield was a continuous yield, and the joint load capacity end value stabilized at a level of approx. 90 kN. No section plastic deformations in the joint were observed after the test either. The most likely cause of the joint yield and systematic decrease of its load capacity was the bad technical condition of the upper and lower shackle bow bolts as compared to the bow shackles utilized in Test 1 (Fig. 7).

a) *b)*

Fig. 7. Bow bolts in joints during testing: a) no. 1; b) no. 2

a) *b)*

Fig. 8. Friction joint 2 shackles after testing (evident yield)

When yielding, bow bolts undergo slight beveling, which results in their increased tension as related to the nominal (generated by nominal tightening torque). Due to the fact that the bow bolts have a considerably reduced cross-section resulting from corrosion (Fig. 7), the bolts undergo significant deformation, which is the cause behind the decrease in section pressure force in the joint and, thus, the decrease in friction force. The low final section load capacity value in the joint (determined at a level of approx. 90 kN) and its character (lack of stepwise yielding typical of friction joints) are also influenced by the joint surface condition, which is covered with multiple corrosion products and stone dust. However, the extent of this in-fluence is very difficult to determine when considering a joint surface condition that is diversified to such a degree.

The conducted tests revealed the high load capacities of significantly corroded friction joints. This particularly concerns their state before the first yield. As can be observed, even major bow shackle corrosion damage (joint II) does not result in decreased joint load capacity (when it comes to the first yield) when compared to a new non-corroded joint. Thus, it can be assumed that (paradoxically enough) significant friction joint corrosion increases its load capacity. However, this concerns the state before the first yield and rupture of the corroded joint. Because of this, under conditions of major frame corrosion and the simultaneous “transformation” of friction joints into corroded arch joints, and in the case of no arch yielding occurring in the overlaps, questions of friction joint load capacity can be disregarded when qualifying corroded frames as suitable for further use, while the corroded frame load capacity assessment itself can be limited to arch strength.

4. SUMMARY AND CONCLUSIONS

The studies of very heavily corroded joints have shown that corrosion has a significant influence on the locking effect of sections in a joint. Depending on the condition of the shackles in a joint (which determine the section pressure force), corrosion may result in a complete blocking of the joint or a situation where its load capacity is much greater than the nominal load capacity. Paradoxically, this leads to an increase in the frame load capacity, as it then changes its characteristics from yielding to rigid. However, this occurs at the cost of its yielding capacity and results in hazardous situations where the support becomes rigid (which is unfavorable, particularly when faced with the possibility of rock mass tremors or deformational load occurrence). The low friction joint load capacity after the first yield (after the breakage of the adhesive joint) may be a cause for concern as well. It must also be taken into consideration that the maximum load capacity of the (rigid) frame decreases together with the progressing corrosion.

Due to the fact that the presented studies are of a pilot character, while the obtained results reveal a very significant influence of corrosion on the support operational safety, the studies of corroded joints will be continued using a larger number of samples and various types of shackles.

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