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# Fiber ropes in a mining environment

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**ABSTRACT** High Modulus – High Tenacity (HM-HT) fiber ropes are increasingly used in mining due to their corrosion resistance, high breaking force, good bending flexibility, and lower density compared to steel wire ropes. These properties facilitate easier handling and higher payload capacities, especially beneficial for deep hoisting applications. Standards such as SABS 0294 (South Africa) and TAS (Germany) highlight the suitability of these fibers for mining hoists. At depths of 3,000 m, HM-HT fiber ropes offer a payload three times greater than steel ropes and potentially longer service lives due to lower loading.

**KEYWORDS** High Modulus – High Tenacity (HM-HT), fiber ropes, mining, deep hoisting

# 1. Introduction

HM-HT fiber ropes (high modulus – high tenacity) are gaining more and more attraction due to their outstanding characteristics: no corrosion, high breaking force, good bending flexibility and lower density compared to steel wire ropes. The last two resulting in an easy handling. The preeminent possibilities of these fiber ropes for the mining industry shall be underlined by figure 1.

| **rope** | **rope diameter dN [mm]** | **min. breaking force Fmin [kN]** | **linear density Tt [kg/m]** |
|---|---|---|---|
| wire rope: 48 6x19S-FC 1770 U sZ | 48 | 1 349 | 8,58 |
| HM-HT fiber rope: TechnaOne | 48 | 1 600 | 1,76 |

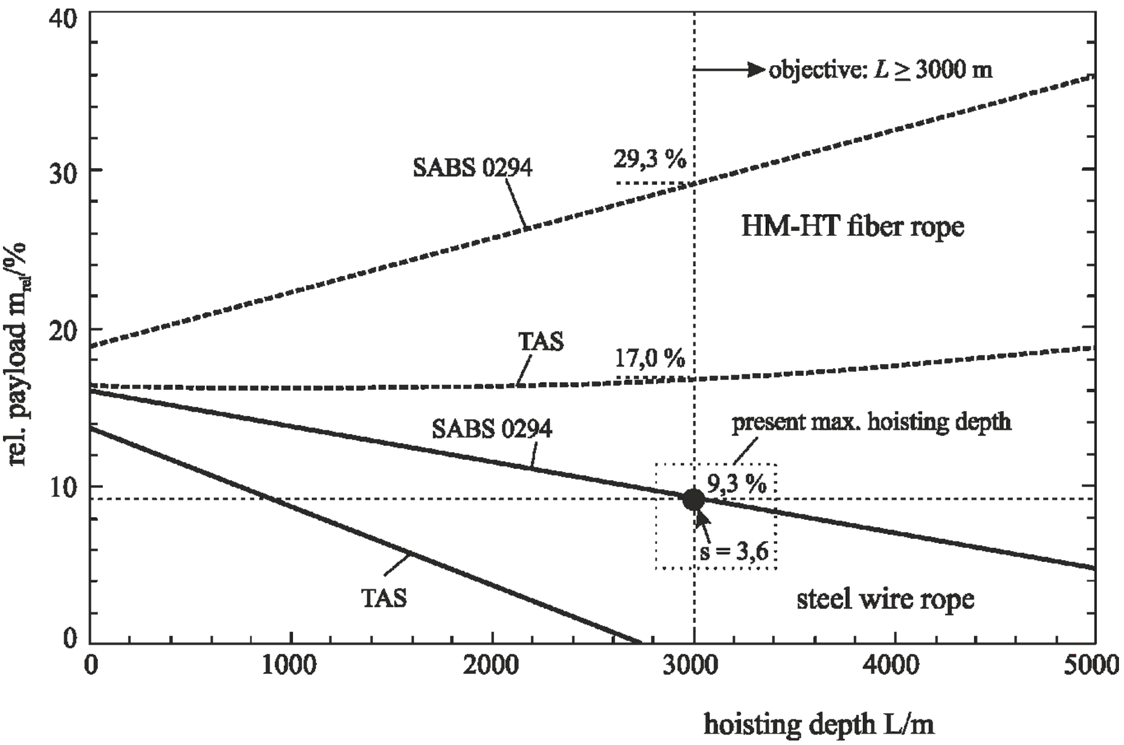


**Figure 1:** HM-HT fiber rope versus steel wire rope; according [1]

A high tenacity in combination with a low density (see table 1) leads to a high payload because of a lower rope mass. With increasing hoisting depths this advantage becomes more important and predestines HM-HT fiber ropes for mining hoists. In figure 1 two standards for mining hoists are shown: SABS 0294 /2/ from South Africa and TAS /3/ from Germany. Hoisting depths of ≥ 3 000 m (like in South African gold mines) can be achieved with steel wire ropes, because the South African standard allows a reduced safety factor. For this hoisting depth the safety factor s is 3.6. To maintain a sufficient service life with this safety factor a high D/d-ratio (bending diameter/rope diameter) of D/d ≥ 75 is necessary. With an increasing hoisting depth the safety factor decreases but the rope mass of the fiber rope does not increase accordingly. This leads to a rising payload for the HM-HT-rope with increasing hoisting depth. For a hoisting depth of 3 000 m the payload for the fiber rope is three times bigger than the payload for the steel wire rope. According TAS the fiber rope can also have a longer service life, because of the lower level of loading. The following equations shall explain the term relative payload $m_{rel}$, given in figure 1:

$$m_{rel} = \frac{m_F(L)}{m_{Ref}} \tag{1}$$

with max. payload $m_F$ of reference steel wire rope $m_{Ref}$:

$$m_{Ref} = \frac{F_{min}}{g} \qquad (\mathrm{s} = 1, \mathrm{L} = 0\ \mathrm{m}) \tag{2}$$

$$m_F(L) = \frac{F_{min}}{s \cdot g} - T_t \cdot L = total\ mass - rope\ mass \tag{3}$$

with

$$T_t = \frac{mass}{length} \text{ … linear density}$$

Until now there have been just a few studies testing ropes under mining conditions. But there is a need for knowledge about the behavior of fiber ropes in a mining environment. Besides other things the special conditions of this environment are challenging: high humidity in ore mines and low humidity but high amounts of dust in salt and potash mines for instance.

## 2. Investigations

The investigated fiber types are listed and compared to steel in table 1. In this table, the chosen steel type corresponds to the highest rope grade according EN 12385-4: Stranded ropes for general lifting applications. The parameter breaking length means the maximum length of fiber that could be held in a vertical direction without breaking.

The linear densities (the amount of mass per unit length, called titer Tt) of the three yarns were 1670 dtex (= g/10 000 m) for Technora® and Vectran® and 1760 dtex for Dyneema®.

In a first test trial 12-strand braided ropes (diameter: 6 mm) made out of two different batches were put for 12 weeks on the floors of the research mine “Reiche Zeche” of the TU Bergakademie in Freiberg, Saxony (a former ore mine) and a former salt and potash mine in northern Thuringia. They were in close contact with the mining water and mud in the research mine and with the salt respectively potash in the mine in Thuringia. After these 12 weeks they were recovered and send to the University of Chemnitz for inspection and tensile tests. The results of these tensile tests are presented in figures 2 and 3.

A loss in breaking force occurs for all three fiber types, which were deployed in the ore mine. The highest reduction showed the UHMW-PE Dyneema® with a mean value of the deployed ropes that is 25 % lower than that of new ropes. The mud and mining water had a pH of 4-5 (acidic) and a temperature of 13 °C, which should not have any effect on the used fiber materials. Especially for Dyneema® water/humidity can be excluded as a reason for the loss in breaking force, because PE almost absorbs no water.

**Table 1:** Comparison steel to used HM-HT fiber types (manufacturer data)

| trade name | Dyneema® SK75 | Technora® T221 | Vectran® T97 | steel |
|---|---|---|---|---|
| manufacturer | Koninklijke DSM N.V. | Teijin Aramid BV | Kuraray Co., Ltd. | various |
| polymer type | ultra high molecular weight polyethylene (UHMW-PE) | aromatic co-polyamide | aromatic polyester | - |
| tenacity $R_m$ [N/mm²] | 3600 | 3400 | 3200 | 2160 |
| density ρ [g/cm³] | 0,975 | 1,39 | 1,41 | 7,85 |
| breaking length $L_R$ [km] | 378 | 249 | 229 | 28 |
| melting point $T_m$ [°C] | 145 | 500 (decomposition) | 480 (decomposition) | ≈1500 |

Figure 5 (left) shows a photomicrograph of the cross section of a braided fiber rope. It shows that the mining water and solid particles fully penetrated into the rope. One possible reason for the loss of breaking force could be the circumstance that these particles are acting as abrasives that destroy the fibers during the tensile tests. But it is unlikely that just this effect solely is responsible for that.

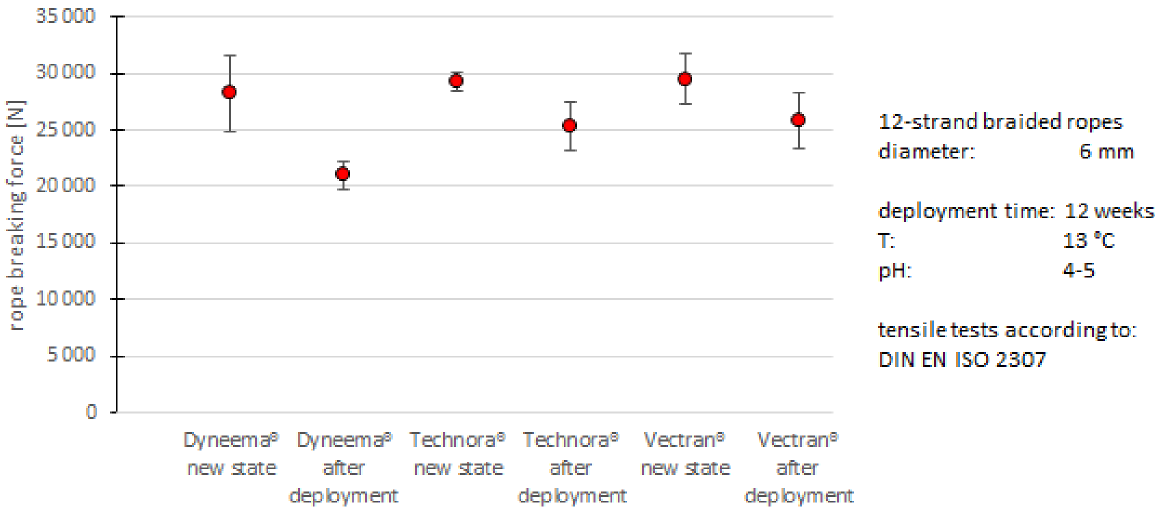


**Figure 2:** Rope breaking force after deployment in an ore mine (ropes w/o sheath)

A DSC[1]-Analysis performed on the Dyneema®-samples showed differences between the new rope (without environmental influences) and the deployed samples, which may be an indication of polymer degradation. However, the reason for that degradation is yet unknown. Further investigations on this topic need to be conducted. The environment of the potash mine has no influence on breaking force of the ropes as figure 3 shows.

[1] *Differential Scanning Calorimetry – a thermoanalytical method to measure the amount of absorbed or emitted heat to increase or decrease the temperature of a sample as a function of temperature. The resulting curves of heat flux versus temperature are specific for each polymer and show glass and phase transitions and effects like degradation /4/*

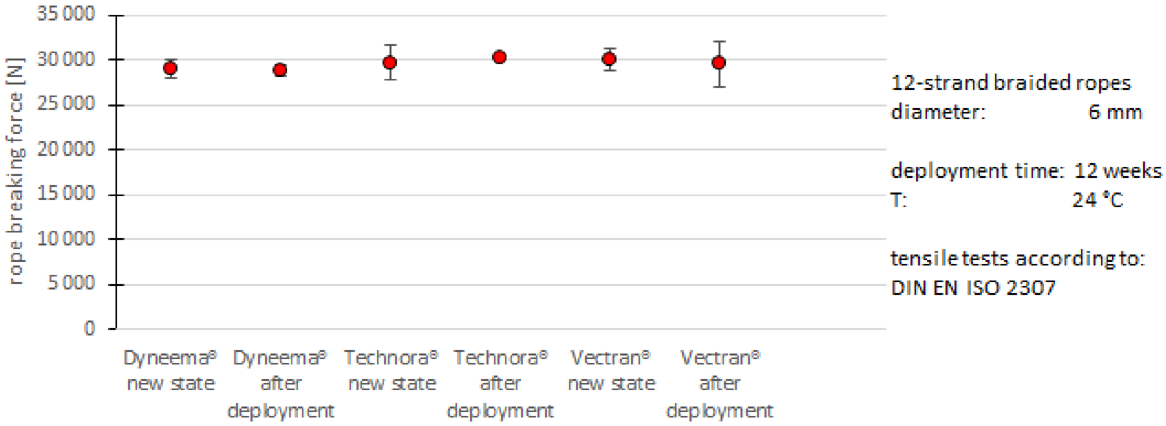


**Figure 3:** Rope breaking force after deployment in a potash mine (ropes w/o sheath)

In another test trial 12-strand braided ropes (diameter: 6 mm) were put for 12 months in brine (pH 6.7; basic) and a slurry, like it is used for backfilling in salt and potash mines because it was planned to use them for a new type of dam for backfilling applications. Figure 4 states that brine and slurry has an effect on rope breaking force on all three fiber types. The pH of the brine should not have any effect but the penetrating particles and an unknown reason for polymer degradation like mentioned above could be responsible.

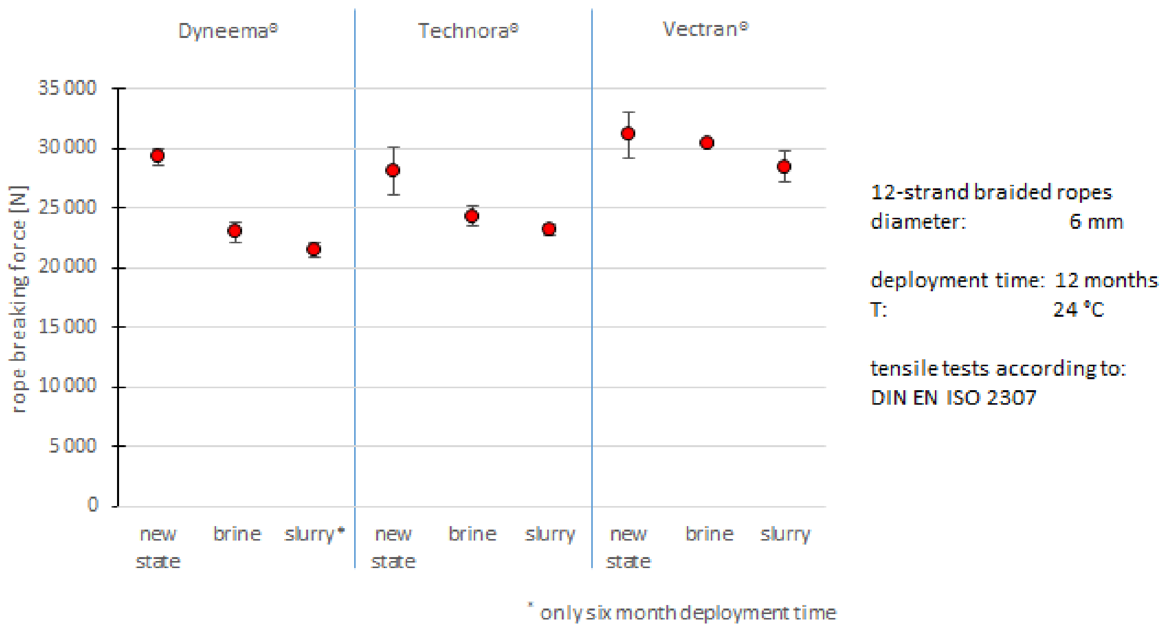


**Figure 4:** Rope breaking force after deployment in brine and slurry

To limit the penetration of water and dirt into the ropes and to reduce the loss in breaking force a 32-stranded sheath made of Polyester-fibers (type 1W70, linear density of the yarn: 1100 dtex) was braided around the HM-HT fiber ropes. The influence of this sheath after laying for 12 weeks on the floor of the former ore mine in Freiberg is shown in figure 5 and figure 6.

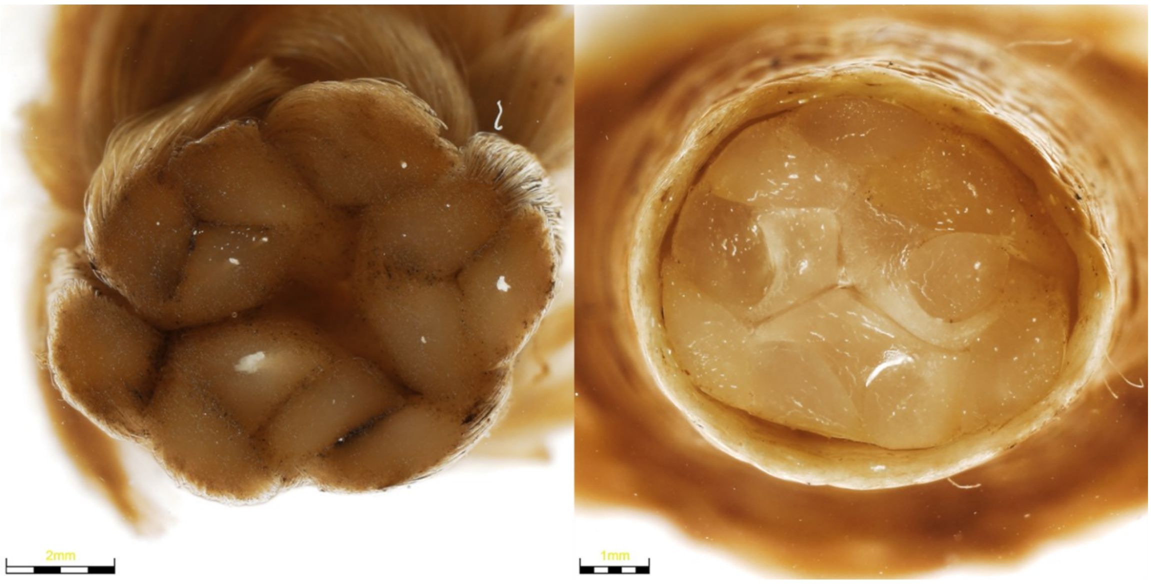


**Figure 5:** Left – 12-strand braided rope; right – rope with braided sheath after deployment on floor of ore mine

It can easily be seen that the outer sheath limits the amount of particles getting into the core of the rope and that the breaking force almost stays the same. Only the dispersion of the measurement values increases.

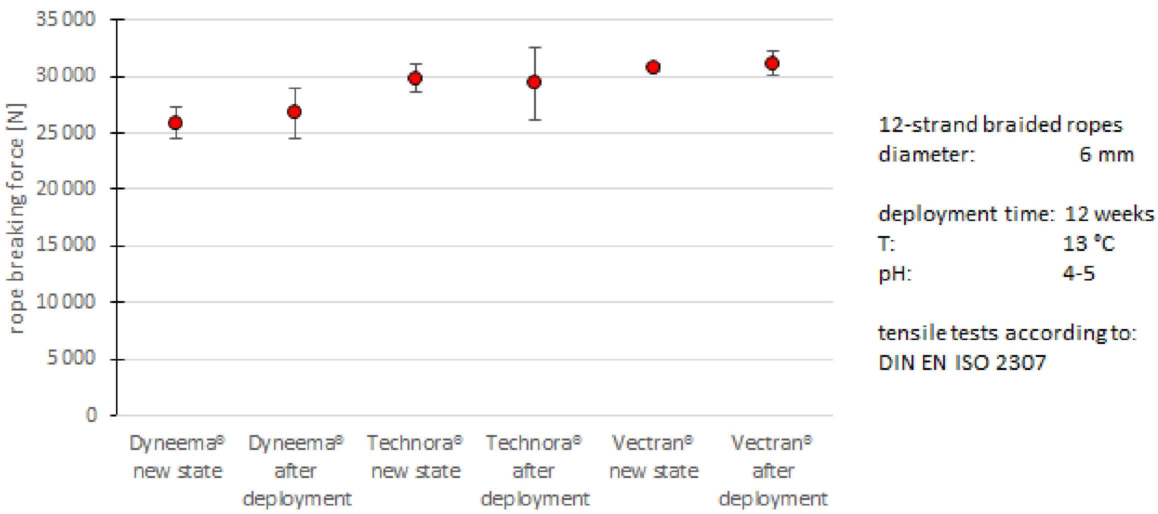


**Figure 6:** Influence of braided sheath

Along with tensile loading in most technical applications bending loading occurs. Therefore, in a last test trial CBOS (cyclic bending over sheave) was performed on CBOS test benches in the research mine in Freiberg and in a laboratory at Chemnitz University in parallel. During this test a rope is driven by a traction sheave and bended over a second (smaller) sheave, called the test sheave (working principle of passive sheave and active rope). The rope travels for a certain length (the stroke sb) in one direction and then the same stroke back. For this trial EOSTEN® was used as UHMW-PE-fiber. It has a lower tenacity of 3 000 N/mm² (resulting in a lower breaking length) when compared to the date given in table 1. The rope design was the same as in the first two test trials. A comparison of these two tests is shown in figure 8. A stroke sb of 500 mm, a bending frequency fb of 12 cycles per minute and a D/d-ratio (bending diameter/rope diameter) of 25 were the test parameters. The three different levels of rope tension correspond to the applied rope tension forces of 2 000 N, 3 500 N and 5 000 N. This means approximately 7 %, 12 % and 17 % of the rope breaking force. It is important to state that the motion profile was not sinusoidal but trapezoidal with an acceleration ramp, a phase of constant velocity and a deceleration ramp. The reason for that is that this kind of motion profile corresponds to that of real technical applications.

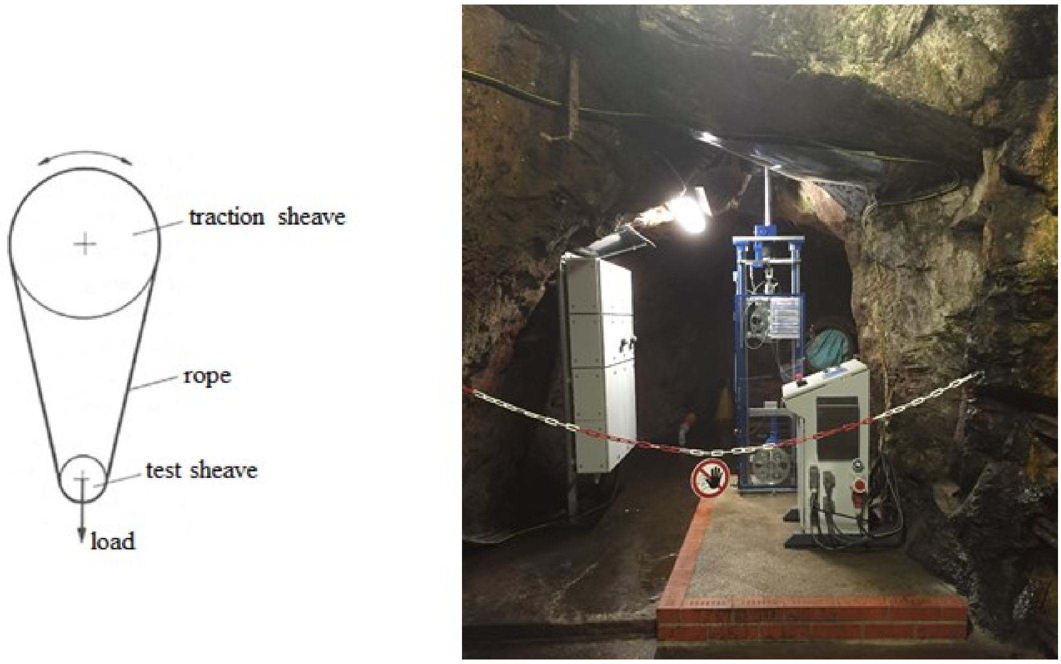


**Figure 7:** CBOS scheme (left, according /5/) and CBOS test bench in ore mine (right)

The number of cycles to failure reached in the mine are in almost all cases lower than those reached in the laboratory. Only the lowest and the highest rope tension within the Eosten®-trials shows the same level of numbers of cycles to failure for laboratory and mine. Technora® has the largest reduction and with increasing rope tension the loss becomes even bigger. For the highest rope tension the loss is approximately 70%. The reason for that reduction is yet unknown, but the above mentioned polymer degradation maybe responsible for this effect.

# 3. Conclusion

It has been found, that a mining environment has a significant influence on HM-HT fiber rope breaking force and cycles to failure. A braided sheath can help to overcome a loss in breaking force.

Further investigations are needed to see, whether a braided sheath can also prevent a loss in cycles to failure during a CBOS-test or not.

As stated above, additional investigations need to be conducted to further understand the effects of decreasing breaking force, especially polymer degradation.

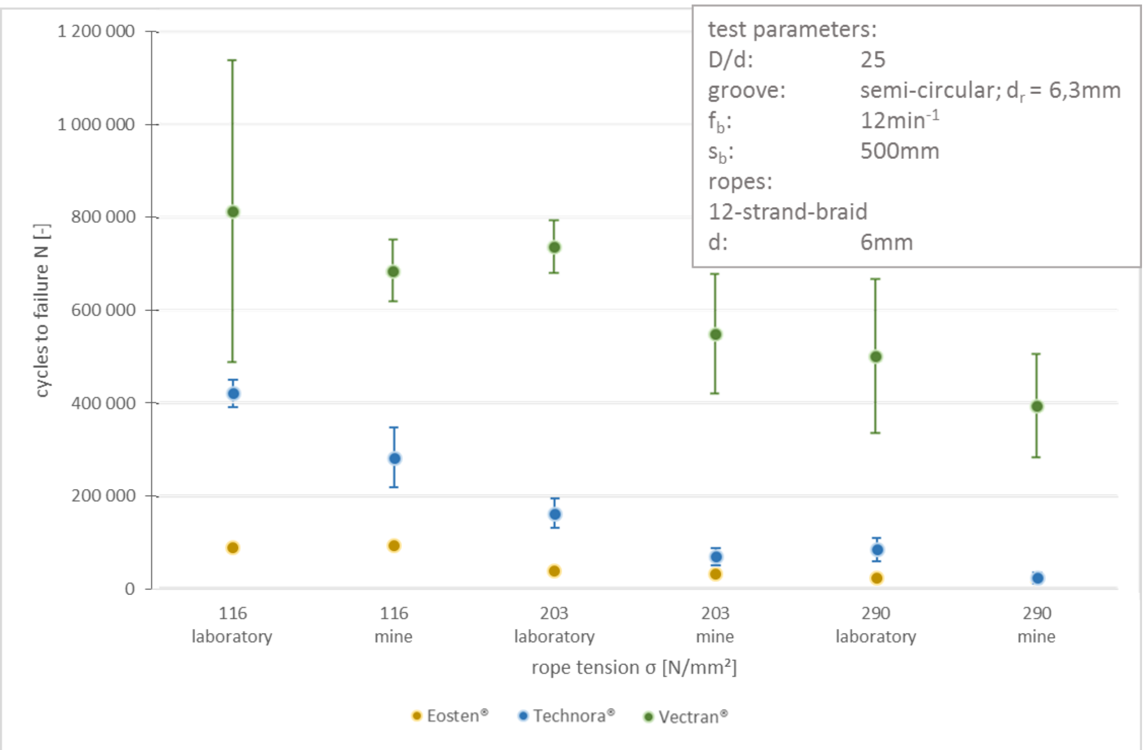


**Figure 8:** CBOS in laboratory versus CBOS in an ore mine

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