TENSILE STRENGTH OF STEEL ROPES OF DIAMOND WIRE SAWS

Siniša DUNDA and Trpinir KUJUNĐIĆ

Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, Pl. Ivana Primera 6, HR-10000 Zagreb, Croatia

Key-words: Steel ropes, Diamond wire, Natural stone

The efficiency of diamond wire saw upon exploitation of natural stone depends on the right choice of the constructional and technological factors of the machine, diamond wire and conditions, and way of exploitation in the particular kind of the rock. One of these parameters is the steel rope of diamond wire.

A long-standing work on testing and certifying of hoisting ropes, experience and knowledge acquired upon these testing, aroused us to a detailed analysis and testing of the ropes which are used in diamond wire shaping. The paper presents the results of tests of steel ropes of diamond wire and the tests of rope joints i.e. tensile strength which can resist the joints between separate rope sections. The suggested idea regarding construction desings of steel rope of diamond wire, which is used in natural carbonate stone exploitation, is based on this experimental testing of steel ropes.

Introduction

A cutting element of a diamond wire saw is a diamond wire enclosed into the endless flow.

Note: The term diamond wire comprises a completely shaped cutting tool, which consists of a steel rope with threaded diamond beads, springs, protecting and blocking spacers and joints. The term "diamond wire" itself is not totally correct, because the steel rope, as a part of this wire, consists of the wires. However, this term has been accepted in English and many other world languages (diamantato - Ital., dijamantna žica - Croat., fil diamante - French, hilo diamantado - Span.), so it is going to be used in the further text.

The type and quality of the diamond wire, including the corresponding condition of the application in the particular rock type, have the crucial impact on the efficiency of the sawing. The correct choice of the construction and characteristics of diamond saw with the corresponding condition of its application considerably influence its durability. The characteristics of diamond wire are determined by its construction as: type and shape of the beads, number of beads i.e. their pitch, type and number of springs, spacers of protective rings and joints. Steel rope is the core of diamond wire. Other wire elements are threaded on it, which together make up a cutting tool, which is the important part of this tool. Each breaking of the rope means direct loss of 3-5 beads. When the rope breaks there is a strike against the stone. Due to the fact that diamond beads do not stand dynamic strikes, in this moment a great number of beads is damaged, although this cannot be seen with the naked eye. Although they are very hard, diamonds are also very brittle and have, as all other crystals, planes of lower resistance. Therefore, diamond beads cannot stand higher impact loads.

Upon operation the rope is stressed by tension, bending, twisting and crushing. It is corroded by cooling water which is mixed with crushed stone particles and diamond beads and is under impact of internal forces due to its own hardness andbrittleness. Therefore, the rope must have a high tensile strength, good elasticity, corrosion resistance and a relatively small mass.

Theoretical contemplations

The stresses, to which a steel rope of diamond wire is exposed during operation, do not depend on tensile stresses only but also on the stresses caused by bending of the rope on the driving wheel, positioning pulleys and the cut itself. They also depend on the stresses by the forces caused by friction resistance in the cut, wire bending due to stretching of the thread line as well as on dynamic stresses upon normal transfer of force especially in exceptional cases. Resonance can also appear due to vibrations of diamond wire at the exit from the cut.

Key-words: Steel ropes, Diamond wire, Natural stone

The efficiency of diamond wire saw upon exploitation of natural stone depends on the right choice of the constructional and technological factors of the machine, diamond wire and conditions, and way of exploitation in the particular kind of the rock. One of these parameters is the steel rope of diamond wire.

A long-standing work on testing and certifying of hoisting ropes, experience and knowledge acquired upon these testing, aroused us to a detailed analysis and testing of the ropes which are used in diamond wire shaping. The paper presents the results of tests of steel ropes of diamond wire and the tests of rope joints i.e. tensile strength which can resist the joints between separate rope sections. The suggested idea regarding construction desings of steel rope of diamond wire, which is used in natural carbonate stone exploitation, is based on this experimental testing of steel ropes.

Introduction

A cutting element of a diamond wire saw is a diamond wire enclosed into the endless flow.

Note: The term diamond wire comprises a completely shaped cutting tool, which consists of a steel rope with threaded diamond beads, springs, protecting and blocking spacers and joints. The term "diamond wire" itself is not totally correct, because the steel rope, as a part of this wire, consists of the wires. However, this term has been accepted in English and many other world languages (diamantato - Ital., dijamantna žica - Croat., fil diamante - French, hilo diamantado - Span.), so it is going to be used in the further text.

The type and quality of the diamond wire, including the corresponding condition of the application in the particular rock type, have the crucial impact on the efficiency of the sawing. The correct choice of the construction and characteristics of diamond saw with the corresponding condition of its application considerably influence its durability. The characteristics of diamond wire are determined by its construction as: type and shape of the beads, number of beads i.e. their pitch, type and number of springs, spacers of protective rings and joints. Steel rope is the core of diamond wire. Other wire elements are threaded on it, which together make up a cutting tool, which is the important part of this tool. Each breaking of the rope means direct loss of 3-5 beads. When the rope breaks there is a strike against the stone. Due to the fact that diamond beads do not stand dynamic strikes, in this moment a great number of beads is damaged, although this cannot be seen with the naked eye. Although they are very hard, diamonds are also very brittle and have, as all other crystals, planes of lower resistance. Therefore, diamond beads cannot stand higher impact loads.

Upon operation the rope is stressed by tension, bending, twisting and crushing. It is corroded by cooling water which is mixed with crushed stone particles and diamond beads and is under impact of internal forces due to its own hardness andbrittleness. Therefore, the rope must have a high tensile strength, good elasticity, corrosion resistance and a relatively small mass.

Theoretical contemplations

The stresses, to which a steel rope of diamond wire is exposed during operation, do not depend on tensile stresses only but also on the stresses caused by bending of the rope on the driving wheel, positioning pulleys and the cut itself. They also depend on the stresses by the forces caused by friction resistance in the cut, wire bending due to stretching of the thread line as well as on dynamic stresses upon normal transfer of force especially in exceptional cases. Resonance can also appear due to vibrations of diamond wire at the exit from the cut.
Ropes were tested in the laboratory after samples were taken from Brač. The observed ropes were replaced due to deterioration. After a detailed visual examination, the tests of breaking strength, bending, and torsion were also conducted. The results of these examinations are presented in this paper.

The testings of the deteriorated ropes have pointed to the difference of decrease of tensile, torsion, and bending strengths. The main cause of wire deterioration appeared to be corrosion, rubbing, and crushing of the rope. These elements are the places of the reduced wire resistance. It was determined that the wire joints are especially sensitive elements of diamond wire. The sudden changes of tensile strengths and the sudden repeated axial impacts, which appear upon the start-up of the saw after the break, have the highest effect on the links of the particular rope sections. These are therefore critical areas especially when the sawing angles are more acute. In order to find out if there is and how much is the difference between breaking load of the rope and braking load of the joint on the rope, we conducted additional laboratory testings, the results of which are presented in this paper.

### Tests of the breaking load of the rope and joints

The former testings comprised testing of various types and constructions of ropes, which are used to form a diamond wire. In the meantime most of the users in Croatia have accepted the round strand rope as the most useful one (Fig. 3) with constructions (1+6+12)+6(1+6). This rope construction proved as the best one in former testings too. Therefore, these testings comprised determination of breaking load of the rope of this construction and breaking load of the same ropes connected by two kinds of joints. The ropes made by 4 manufacturers were tested and sleeve couplings and joints with “male-female” threads were used for connecting. Connecting was done on a standard device which is used upon shaping of diamond wire (diamond wire bench assembling unit) by the workers of particular users in the way as they do it for their everyday use. Although all the ropes had the same basic construction they differed among each other to a certain extent in the strength of steel and minor construction details.

### Experimental work

In the company Jadrankamen-Pučišća (the island of Brač) the consumption of different rope types was observed in order to determine the characteristics of diamond wire rope and changes of these characteristics after the operation within a certain period of time. The observed ropes were tested in the laboratory after samples were taken from the new ropes and the same ropes after particular ones had to be replaced due to deterioration. After a detailed visual examination, the tests of breaking strength, bending, and twisting of the rope were also conducted. The results of these testings were presented at the 10th International Conference: Investigation, Production and Use of Steel Wire Ropes - Slovakia, 1998 (Dunda, S. & Kujundžić, T.: Diamond wire saws). In these testings the real breaking load was only determined by breaking of the rope as a whole, in difference to the earlier testings, when this load was determined by testing of specific wire samples and summing up their values. Upon the testing of the rope by its breaking as a whole appears gradual breaking of some wires within specific force and loosening of the strength (Fig. 4). The indicator of the testing instruments registers the load which causes the damages of some wires, not the rope braking. This load is regarded as relevant for determination of the allowed tensile strengths.
During the testings of breaking load of rope joints breaking was in most cases caused by pulling out of the rope from the joint (Fig. 5), whilst only in a small number of cases the ropes broke along the edge of the joint (Fig. 6). Strictly speaking, during the testings of joints with “male-female” thread the rope was pulled out from the joint in

<table>
<thead>
<tr>
<th>ROPE NO.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum breaking load, N</td>
<td>17 260</td>
<td>12 259</td>
<td>15 838</td>
<td>15 966</td>
</tr>
<tr>
<td>Maximum breaking load, N</td>
<td>18 290</td>
<td>14 367</td>
<td>17 211</td>
<td>16 476</td>
</tr>
<tr>
<td>Average breaking load, N</td>
<td>17 898</td>
<td>13 779</td>
<td>16 721</td>
<td>16 051</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THREADED JOINTS ON ROPE NO.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum breaking load, N</td>
<td>4 492</td>
<td>4 904</td>
<td>4 521</td>
<td>4 865</td>
</tr>
<tr>
<td>Maximum breaking load, N</td>
<td>6 100</td>
<td>6 865</td>
<td>6 473</td>
<td>6 360</td>
</tr>
<tr>
<td>Average breaking load, N</td>
<td>4 805</td>
<td>5 954</td>
<td>5 374</td>
<td>5 260</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SLEEVE COUPLINGS ON ROPE NO.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum breaking load, N</td>
<td>1 746</td>
<td>-</td>
<td>3 170</td>
<td>-</td>
</tr>
<tr>
<td>Maximum breaking load, N</td>
<td>3 785</td>
<td>-</td>
<td>3 310</td>
<td>-</td>
</tr>
<tr>
<td>Average breaking load, N</td>
<td>3 462</td>
<td>-</td>
<td>3 240</td>
<td>-</td>
</tr>
</tbody>
</table>
86.6% cases and in 13.4% cases the rope broke along the edge of the joint, while the rope was pulled out from all the sleeve couplings.

The concise results of the testings of breaking load of diamond wire ropes and joints on them are presented in the Table 1. The names of specific rope manufacturers are not stated in the Table but they are replaced by the numbers 1, 2, 3 and 4. 25 rope samples (total of 100) were tested from each manufacturer including the total of 100 joints with "male-female" threads and 50 sleeve couplings. The average figures of breaking load of the rope and joints present the mean value of 23 tested samples, because the lowest and the highest values are not included in this average value.

![Fig. 6. A more rare way of breaking of rope joints](image)

**Analysis of the results**

The results of the testings (Tab. 1) show that the steel rope of diamond wire, which is used upon sawing of carbonate stone, can resist to approx. 3 times higher tensile strength than the joints connected by "male-female" threads and approx. 5 times higher strength than the joints connected by sleeve couplings. Upon testing of complete rope breaking the average breaking load was 17 898 N for the ropes no. 1, 13 779 N for the ropes no. 2, 16 721 N for the ropes no. 3 and 16 051 N for the ropes no. 4. The highest average value of breaking loads of joints with "male-female" threads was only 5 954 N (ropes no. 2) and 3 462 N (ropes no. 1) for the joints connected by sleeve couplings.

These testings clearly show that the rope can resist to a considerably higher breaking load than the joints can. Accordingly, the critical points of breaking are joints too, not just ropes. This means that it is not necessary to have ropes of high breaking load. More important is for them to be as elastic as possible. Therefore, the softer wire material can additionally increase the rope elasticity.

The diamond wire rope must have a small cross-section and mass but high tensile strength. Such a rope must be elastic and resistant to crushing, torsion, abrasion and corrosion. It is very difficult to select the rope construction which meets all the requirements at the same time, since some of them exclude one another. The wires of larger diameter have higher tensile strength but lower bending strength at the same time and v.v. By increase of wire hard-
with decreased internal friction, which appears upon bending in the cut and passing along the pulleys and driving pulley. If the rope had stiffly braided hempen core of appropriate dimensions, it would increase its softness and reduce the friction and stress of the wires upon one another. However, it was thought that the application of the ropes with hempen core on diamond wire saw was not purposeful since such a rope has a decreased metal cross-section. Small diameter of diamond wire rope has already a small metal cross-section, so its additional decrease would substantially reduce the breaking load of the rope. The ratio of the metal cross-section and the cross-section of the circumscribed circle around the cross-section of the normal strand ropes with hempen core is approx. 0.47 and approx. 0.75 with spiral strand ropes. The presented laboratory testings of breaking load of ropes and joints show that even a rope with such reduced cross-section would have sufficient i.e. higher breaking load than the joint. This means that standard stranded ropes for general purpose (DIN 3055, DIN 3060) consisting of 6 rounded strands arranged concentrically around hempen core could be used as ropes of diamond wire saws (Fig. 7). Hempen core serves as elastic "placenta" and a reservoir of grease for strands and wires, which also influences the extension of durability of ropes.

Since diamond wire rope is small in diameter (5mm) it is certain that spiral ropes will further be used in a considerable number of cases. The results of the presented testings show that the wires of such ropes should be made of softer steel. In our opinion the ropes should be constructed with fillers. The ropes with round strands have emptiness in the strands which decreases the homogeneity of the rope. In order to reduce the squeezing of the wires in the rope, which is the consequence of these empty spaces, thin filler wires are put among the wires (with some constructions), but they are not load bearing wires. This enables better contact of the wires in strands and better elasticity of the rope. The diamond wire rope has smaller empty spaces in the strands because of the small wire cross-sections (smaller than the usual ones in the filler wires), so the wire filling of the strands would not have any purpose. However, the empty spaces among strands in these spiral strand ropes cause the increased friction and stress of the wires upon one another. Therefore we think that the construction of the rope, which would have hempen (or even better synthetic) fibre filling would show longer durability than the existing ropes. Such possible rope construction (Fig. 8) would not be different than the existing ones, except the fact that it would have synthetic fibres of a small cross-section as a filler. These fillers would increase the homogeneity of the rope, the strands would not have punctual contact, but the contact surface would be spread on the synthetic inserts, which would decrease crushing caused by the elements of the diamond wire (especially beads). This is especially visible upon bending along a small radius of curvature. Synthetic fibres would take over the role of the hempen core to some extent by making the rope softer, but they would not reduce its load bearing capacity, because the metal cross-section would remain the same. The increased softness of the rope would reduce the internal friction upon bending along the pulleys and in the cut, which would decrease deterioration and prolong the durability of the rope.

Fig. 7. Suggested standard stranded ropes with hempen core \([j+6(l+6)]\) and \([j+6(l+6+12)]\)
Sl. 7. Predložena obična pramena s hempen okraškom \([j+6(l+6)]\) i \([j+6(l+6+12)]\)

Fig. 8. Proposal of a new construction of ropes for diamond wire, 1) steel wire, 2) synthetic fibre, 3) diamond beads
Sl. 8. Prijedlog nove konstrukcije v Dane za dijamantnu četka, 1) čelitna četka, 2) sintetična nit, 3) dijamantne perle

Received: 2000-12-14
Accepted: 2001-10-23

REFERENCES