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THE ELABORATION OF A THEORETICAL METHOD FOR THE RELIABLE DETERMINATION OF THE REPERTED APPLICATION OF LIGHT METAL ROOF BARS IN BAUXITE MINING

Summary. The paper deals with the reliability questions of repeated application of light metal supporting systems used in the Hungarian bauxite mines. A theoretical method has been workéd out to analyse the stress and strain state of cyclic bending of light metal roof bars. An analitical expression has also been derived for the determination of fracture initiation on the basis of damage accumulation. According to the theoretical expressions the admissible number of repeated application can be determined. A computer program for carrying out the necessary calculations is also developed. The experimental results obtained from laboratory-tests and mining experiments are in good agreement with the theoretical calculations.

1. INTRODUCTION

In the Hungarian bauxite-mining the application of light metal supporting systems (instead of the previously applied timber supports) were spread in the past decade.
It may be emphasized by more motives:

- owing to their greater load bearing capacity the increasing the width of the rooms (winning boards) becomes possible, assuring on the one hand the increase of ore amount during one working cycle, on the other hand it makes possible to meet the sectional demand of large scale mechanization, which results in the decrease of the cycle time of working period;
- comparing to the roof timber used for only a single setting, the light metal roof bars may be applied in several times decreasing the demand for materials handling in connection with transporting the support structures and increasing the mining capacity. All these together lead to the significant increase of productivity.

The setting of the light metal roof bars is shown in Fig. 1. Hydraulic, servo-props of nominal load capacity of 250 KN are applied also from aluminium based light alloys. In the course of the application the roof bars are deformed due to the roof pressure. Their repeated application can usually be carried out after straightening them. From the deformation in the mine and from the cold straightening, deformation damage is accumulated in the roof bars. Therefore the following essential guestions should be answered for the reliable application of them:

(1) How large deformations can be repaired by cold straightening?

(2) How many times can the deformad and cold straightened roof bars be used without the risk of fracture?

For answering these guestions, it is necessary to know the degree of deformation damage deriving from the deformations in the mine and the following cold straightening. It seems reasonable, to determine the deformation damage accumulated in the roof bars in the function of such a charasteristic parameter, which is measurable with adequate accuracy in a relatively simple manner under mining conditions, too. For this purpose, the residual deflection of roof bars is regarded as the most suitable parameter. For determining the criteria of repeated application the stress - and strain state of roof bars during cyclic bending should be known.

2. THEORETICAL CONSIDERATIONS OF CYCLIC BENDING OF ROOF BARS

The admissible number of repeated application of roof bars can be determined on the basis of damage accumulation. The roof bars can be used as long as the accumulated specific strain work deriving from the residual strains and the cold straightening will reach the value of the specific energy to fracture, characteristic for the roof bar material.

For theoretical analysis the complicated extruded profile of roof bars (shown in Fig. 2.) is substituted with a simplified rectanguiar cross-section, whose sizes have been determined from that consideration that identical bending moment should result in identical deformation in case of the original and the substituting cross-sections, as well.

The roof bars are made of hardened light allong of ALMGSi 1. This material exhibits increased hardening properties. The stress-strain relationship valid for plastic deformation shows good agreement with the Nadai Power rule. At the same time in the technical literature of plasticity the relationschips related to the bending of roof bars of rectangular cross section are only worked out for ideally rigid-plastic and elastic-ideal plastic conditions, respectively. These equations incorrectly describe the stress - and strain state of materials corresponding to the forementioned stress-strain relationship. It made necessary to carry out a theoretical analysis describing the behaviour of the roof bars correctly for elastic-plastic deformations in the case of strongly hardening materials, as well.

For elaborating the method the deformation state was determined in the function of residual deflections. Then the accumulated damage in each cycle could be calculated directly from it. For the simplicity of solution the following assumptions were made:

- the cross-sections remain plains during bending,
- the neutral axis remains in the centre of the bar,
- the Bauschinger effect is neglected.

The bending moment necessary for bending of roof bar of rectangular cross section may be expressed by the formula

$$M = 2\int_{0}^{h/2} y\,\sigma\,b\,dy, \tag{1}$$

where the stress distribution along the cross section may be substituted with the forementioned power rule of hardening

$$\sigma = R_p\left[\frac{\varepsilon}{\varepsilon_p}\right]^{n} \tag{2}$$

Considering the facts mentioned above, the bending moment can be calculated (after elementary conversions)

$$M = 2\,b\,R_p\,\frac{\left[\frac{h}{2}\right]^{n+2}}{\varepsilon_p^{n}\,(n+2)\,\rho^{n}} \tag{3}$$

where: R - the static yield stress,
ε_p - elongation belonging to the yield point,
n - the Nadai Power exponent,
ρ - the curvature radius of the neutral axis of the residually deformed roof bar.

Expressing the constant values in one constant (C) the differential equation of bended roof bar relating to the neutral axis can be written as follows:

$$\frac{d^2y}{dx^2} = -\frac{1}{\rho} = -\left[\frac{M}{C}\right]^{1/n} \tag{4}$$

The roof bars applied in mining carry distributed, or at several points concentrated loads, during straightening they bear essentially concentrated load at one point. This latter load distribution seems to be much more dangerous, therefore its assumption during the analysis increases the safety. Substituting the moment distrubution (corresponding to the concentrated loading) into the equation (4) and integrating it twice, we obtain deflection of roof bar in the function of loading

$$y = -\frac{4C^2}{F^2}\,\frac{1}{\frac{1}{n}+2}\left[\frac{F}{2C}\,x\right]^{\frac{1}{n}+2}\frac{1}{\frac{1}{n}+1} + C_1x + C_2 \qquad (5)$$

It is valid for the plastically deforming "m" section of the roof bars (see Fig. 3.). Considering the boundary conditions, as well as the the solution valid for the "x_o" section of elastic deformation, the determination of C and C constants may be carried out by the following expressions:

$$C_1 = \frac{2C}{F}\,\frac{1}{\frac{1}{n}+1}\left[\frac{F}{2C}\,\frac{1}{2}\right]^{\frac{1}{n}+1} \qquad (6)$$

and

$$C_2 = \frac{Fx_o^3}{6IE} - \left[\frac{F}{2C}\,x_o\right]^{\frac{1}{n}+1}\frac{1}{\frac{1}{n}+1}\,\frac{2C}{F}x_o + \left[\frac{F}{2C}x_o\right]^{\frac{1}{n}+2}\frac{1}{\frac{1}{n}+1}\,\frac{1}{\frac{1}{n}+2}\,\frac{4C^2}{F^2} \qquad (7)$$

where: I - second moment of cross section of the roof bar,
E - the Young-modulus of the material.

Using the equation (5-7) the deformation of the roof bar can already be described. It follows from the inhomogen stress state of the roof bar, that cracks will be initiated in the so-called outermost fibre. Therefore the deformation damages accumulated during the loading cycles and the following straightening should be summarized in there.

The specific deformation damage deriving from one bending cycle (using the symbols of Fig. 4.) can be written as follows:

$$w_1 = \int_0^{\varepsilon_1} \sigma\, d\varepsilon, \qquad (8)$$

which using the previously applied transformations can be rewritten

$$w_1 = R_p \frac{\varepsilon_1^n}{\varepsilon_p^n} \frac{1}{n+1} \tag{9}$$

where: ε_1 the deformation in the outermost fibre during one bending cycle.

The knowledge of relationships for bending of a roof bar of rectangular cross section provides the possibility to take into consideration the cyclic bending as well. In the case of successive bending - and straightening the hardening should not be neglected, i.e. the variable yield stresses due to the strains should be taken into consideration.

The solution and the calculations of the previously derived equations are fairly complicated. Therefore a computer method has also been developed for carrying out the calculations in successive bending-straightening cycles.

The calculations corresponding to the loading - straightening cycles are carried out by the program taking into account the changing material properties because of hardening. This calculations are repeated as long as the accumulated deformation damage (strain-work) in the outermost fibre reaches the value of the specific strain-energy to fracture. Results are printed as shown in Table 1.

Table 1.

Calculation results corresponding to the loading straightening cycles

Wyniki obliczeń cyklu wzmocnienia w stropnicy

Number of cycles	Load F (kN)	Deflection of roof bars f(mm)	Specific strain (%)	Accumulated work w (MJ/m)
1	102 000	156.56	2.71	12.57
2	129 500	156.36	2.61	26.51
3	140 050	156.48	2.57	40.93
4	147 750	156.73	2.55	55.61
5	153 250	157.11	2.53	70.52
6	157 500	156.58	2.50	85.61
7	161 250	157.08	2.50	100.88
8	164 250	156.46	2.47	116.24
9	167 000	156.48	2.46	131.64
10	169 500	156.70	2.45	147.13
11	171 750	156.84	2.44	162.70
12	173 750	156.77	2.43	178.36
13	175 500	156.39	2.41	194.05

The effect of hardening can be seen well from the results: it manifests in the increase of load necessary to produce the same deflection in the consecutive cycles.

The calculations were carried out with several deflections taking into consideration different material properties. Results are shown in Fig. 5. (where N - the number of cycles, f - residual deflections). It can be seen from the diagram that the calculated points fit well on straight lines. This diagram can be used in a simple manner to determine the admissible number of loading cycles in the case of constant deflections.

But because of the stochastic nature of the roof pressure the roof bars are generally deformed in different values of deflections in successive applications. In this case the admissible number of repeated application should be determined using the damage accumulation theory of Palmgren and Miner [3]. On the bassis of it at the moment of crack initiation the following condition must be fulfilled

$$\sum \frac{n_i}{N_i} = 1 \tag{10}$$

where: n_i - means the number of cycles at a certain value of deflections,
N_i - means the number of cycles to fracture at the same deflection.

According to this the admissible number of cycles in a general case can be determined as follows: at each value of deflections (f_i) the number of successive loading and straightening cycles (n_i), and the number of cycles to fracture (N_i) have to be determined. The roof bars can repeatedly be applied as long as the summarized value of (n_i/N_i) ratios reaches the value of unit.

3. EXPERIMENTAL RESULTS

To verify the theoretical relationships derived previously a series of experiments were carried out on ready-made roof bars in a three-point bending device mounted on a universal testing machine of 1 MN nominal capacity.

The roof bars were tested to fracture with repeated loading and strightening cycles. Five roof bars - having approximately the same material properties - were tested: three of them with constant deflections and two with different values of deflections in the successive cycles. The number of cycles to fracture were plotted vs. deflections (Fig. 6.). In this diagram the theoretical curve belonging to the same material properties is also shown. It can be seen that the experimental results fit also on a straight line (in a bilogarithmic diegram) and the experimental and the theoretical curves are in good agreement.

The elaborated method has been succesfully used in the Hungarian bauxite mines for more than ten years. The correctness of the theoretical conclusions and laboratory tests were also justified by mining experiments.

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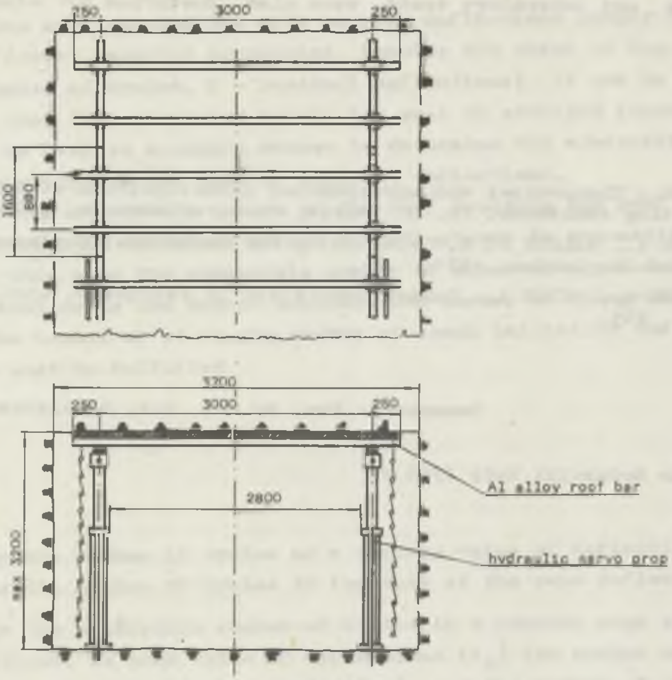

Fig. 1. Setting of the light metal roof bar

Rys. 1. Usytuowanie stropnicy z metali lekkich

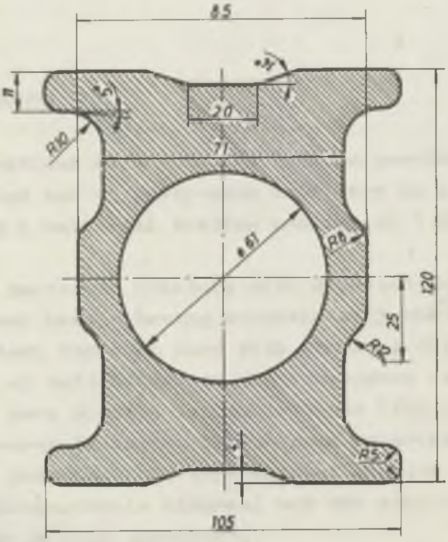

Fig. 2. Profile of the roof bar

Rys. 2. Przekrój przez stropnicę

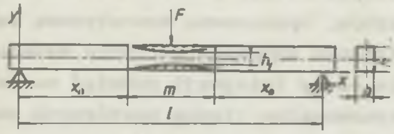

Fig. 3. Plastically deformed section of the roof bar

Rys. 3. Strefa stropnicy odkształcona plastycznie

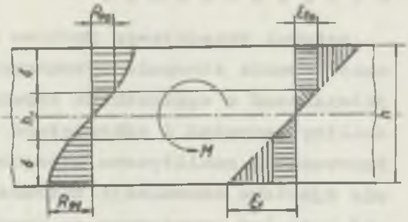

Fig. 4. Bending cycle of the roof bar

Rys. 4. Cykl zginania stropnicy

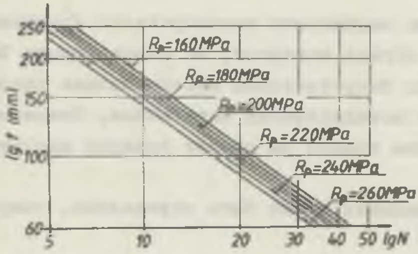

Fig. 5. Results of the calculations, where N is the number of cycle and f is residual deflections

Rys. 5. Wyniki obliczeń, gdzie N jest to liczba cykli a f jest odkształceniem szczątkowym

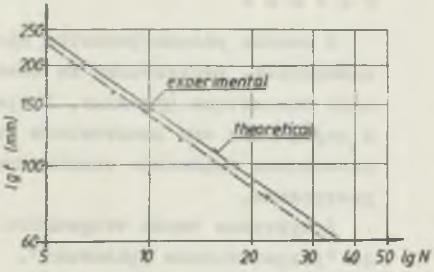

Fig. 6. Calculation results corresponding to the loading straightening cycles

Rys. 6. Wyniki obliczeń cyklu wzmocnienia w stropnicy

OPRACOWANIE TEORETYCZNEJ METODY OBLICZEŃ NIEZAWODNEGO WIELOKROTNEGO ZASTOSOWANIA STROPNIC Z METALI LEKKICH W KOPALNIACH BOKSYTU

Streszczenie

Artykuł przedstawia problem niezawodności w przypadku wielokrotnego zastosowania stropnic wykonanych ze stopów metali lekkich na podstawie doświadczeń z węgierskich kopalń boksytów. Opracowano teoretyczną metodę analizy naprężeń i odkształceń w cyklicznym zginaniu stropnic metalowych. Wprowadzono analityczne naprężenie dla oceny inicjacji pęknięć na podstawie zjawiska akumulacji zniszczeń. Dopuszczalna liczba powtórnych zastosowań może być wyznaczana za pomocą opracowanego równania. Opracowano również program komputerowy dla przeprowadzenia obliczeń. Wyniki badań laboratoryjnych i dane eksploatacyjne okazały się zgodne z wynikami obliczeń teoretycznych. Weryfikację przeprowadzono badając stropnicę w specjalnym trzypunktowym uchwycie do zginania na uniwersalnej maszynie wytrzymałościowej. Stropnice były badane do pęknięcia z powtarzającym się cyklem obciążeń zginających. Badano pięć stropnic, które miały w przybliżeniu te same własności. Trzy stropnice badano przy stałym ugięciu, pozostałe dwie przy różnych następujących po sobie ugięciach. Wyniki badań potwierdziły przewidywania wynikające z rezważań teoretycznych.

РАЗРАБОТКА ТЕОРЕТИЧЕСКОГО МЕТОДА РАСЧЁТОВ НАДЕЖНОГО МНОГОКРАТНОГО ПРИМЕНЕНИЯ НАКАТНИКОВ ИЗ ЛЁГКИХ МЕТАЛЛОВ НА БОКСИТОВЫХ РУДНИКАХ

Резюме

В статье рассматривается проблема надёжности многократного применения накатников, выполненных из сплавов лёгких металлов, на основе опыта Венгерских бокситовых рудников. Разработан теоретический метод анализа напряжения и деформации при циклическом изгибе металлических накатников. Введено аналитическое выражение оценки появления трещин на основе явления аккумуляции разрушения.

Допустимое число вторичного применения может быть определено, опираясь на "разработанные уравнения".

Разработана также программа проведения расчетов на ЭВМ. Результаты лабораторных исследований и эксплуатационные данные совпали с результатами теоретических расчетов. Проверка была проведена путём испытания на изгиб накатников, установленных в специальных трёхчечных держателях на универсальной испытательной машине.

Накатники испытывались до изломов с повторяющимся циклом изгибающей нагрузки.

Испытывались пять накатников, имеющих приблизительно одинаковые свойства. Три накатника подвергались испытанию при постоянном прогибе, два других – при разных, следующих один за другим прогибах.

Результаты испытаний подтвердили данные, предсказанные теоретическим путём.