On the Investment for Conveyor Belting

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Summary

This paper shows some of the actual problems in the efficiency and economics of conveyor belts. The buyer of a belt invests in quality and maintenance with the goal of high availability. However, there are no universal calculating methods (to calculate belt tension, for example) by which investment for purchase and quality and the expenditure for wear and maintenance may be calculated and compared with the resulting availability.

The present existing methods for establishing wear influences and their link back to conveyor belt technology are described. An extensive statistical investigation is suggested which would allow a computerised statistical listing of the lives of as many conveyor belts as possible. By processing these data, it should be possible to create formulas and tables of factors which would allow calculation of the parameters of investment and availability mentioned above. Some problems regarding maintenance are mentioned which may well be solved by the suggested method. Finally, the influence of human behaviour on isolating and preventing causes of wear and damage to conveyor belt systems is discussed. An internationally acknowledged method (QCC) is proposed which may well be adapted to conveyor belt systems in mines.

1. Introduction

The economics of handling bulk materials by conveyors depend to a great extent on the economics of the belting. Conveyor belts can only be economical if they have been designed economically and have a long life expectancy.

Conveyor belting may cost as much as the entire remaining mechanical structure of a belt conveyor. This often lies in the range of several million Dollars. The belt not only has to be bought, it also has to be maintained and removed and replaced later on, owing to wear or damage. The total investment necessary for the continuous availability of operable conveyor belt lengths in a mine is therefore an important factor in the calculation of the economy of conveyor haulage. Maintenance is one of the most important factors as is shown by the following examples:

Urban [1] estimates that for steelcord belts in the lignite industry, one engineer is required for the maintenance of 3,000 to 4,000 m² of belt surface.

Schönleben [2] reports that in the mines of the Bayerische Braunkohle-Industrie Schwandorf, the loss of length of originally purchased belting amounts to 25 % after 8 years, and 60 % after 11 years.

Josteit [3] reports that in the Rheinische Braunkohlenwerke, 2.57 hours of maintenance work have to be taken into consideration per year and per square metre of fabric belting. In the case of steelcord belts, it is 0.54 hours for maintenance work. This cost is equal to approximately 20 % of the total operating costs of the conveyor system.

Figs. 1, 2, 3 and 4 show the presently existing conveyor belt designs considered here.

2. Investment for Conveyor Belting

Naturally, the users of conveyor belts are interested in keeping the total investment for the belt low and in extending the period of usage as far as possible before replacement is necessary. The user therefore invests in the quality and in the maintenance of a conveyor belt expecting a high availability in return. The question now arises regarding the relation between a belt's availability and the investment in its quality and maintenance, and, whether it is possible to calculate these factors in advance. Here, a comparison with a car tyre is useful.

The buyer of a car tyre also looks for a high, but nevertheless, economical availability of the tyre. He compares the yearly expenditure for the tyre by comparing its purchase price and replacement cost with the generally known availability — in this case, the mileage. The buyer selects a type of tyre according to these data. He is neither interested in the construction of the tyre, e.g. the thickness of the tread, the tensile strength of the rubber cover compounds, etc., nor does he calculate the running resistance, friction, air pressure or tensile strength of the tyre carcass. He assumes that these values have been correctly determined by the manufacturer. He normally does not include the repair of the tyres in the calculation, which, in fact, occurs rarely. However, he calculates replacements.

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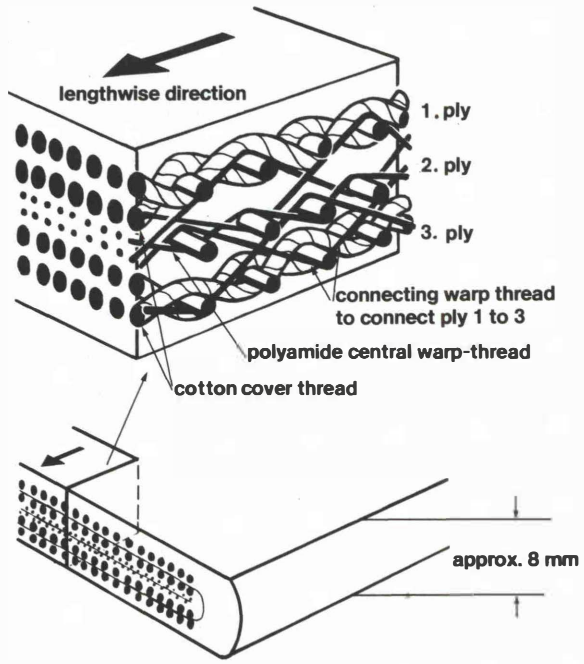


Fig. 1: Schematic design of a mono-ply-belt

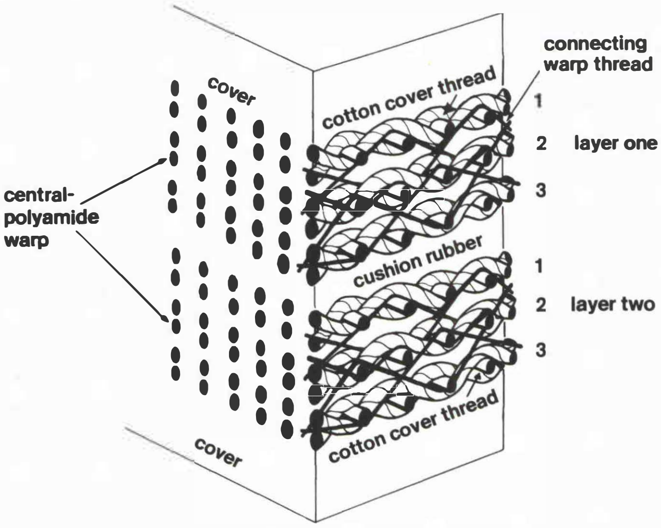


Fig. 2: Schematic design of a two-ply-belt

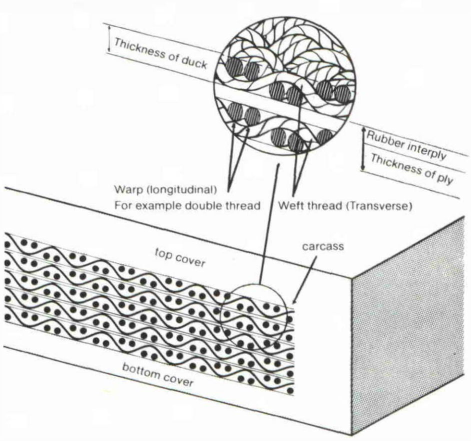


Fig. 3: Schematic design of a poly-ply-belt

This is different with the conveyor belt. While purchasing a belt, the buyer usually does not compare in advance the investment in purchase, maintenance, quality and spares with the resulting availability, by means of a calculating method as would be appropriate for achieving the highest possible efficiency of the belt. Instead, the buyer often looks only for a low purchase price, low stock of spares and, under some circumstances, even accepts afterwards a higher investment for maintenance work. At present, there still is no method available for calculating investment and availability factors in advance.

However, when a belt is being purchased, the drive capacity, belt tensions, etc., are calculated very elaborately. These calculating methods are standardized (DIN 22101, for example). Although they determine the investment for the purchase and replacement of a conveyor belt, they do not reveal anything about the availability to be expected or about the investment for this. Furthermore, they are not as exact as should be for a correct determination of investment. For example: In order to arrive at the suitable belt type, an empirically established safety factor S is chosen, for instance, which leads to the required belt breaking load. Besides the geometrical dimensions and other service conditions, it is this safety factor which considerably influences the investment in purchasing and replacing a belt. In some countries, the belt is purchased according to the rating, that is, the working tension of the belt. There, the safety factor is the sole concern of the maker of the belt.

Only some empirical values are given in DIN 22101 for the safety factor under normal, stationary operating conditions.

Because of its influence on the investment, one should critically consider the safety factor, which should be as low as possible. Also, it is better to substitute the empirical method with a calculation [4], which is described here in some detail, if this diversion from the original topic of this paper is allowed.

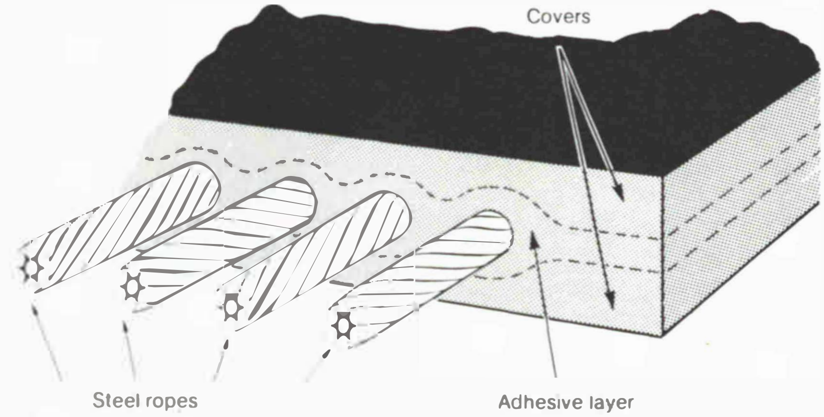
3. Calculating the Conveyor Belt

The conveyor belt is elastic, much like a spring. Therefore, a tension elongation characteristic can best be established after the belt specimen has been pretensioned numerous times (Figs. 5, 6). By means of this characteristic, the different existing tensions and elongations of the belt operation which are to be correlated can be identified. A conveyor belt should not be loaded above 60 % of the belt breaking load without incurring damage. There should be a safety margin of about 20 % to cope with overloading, impact, etc. This means that at no time and at no place should the tension in a belt exceed 40 % of the belt breaking load ($S = 2.5$). These 40 % of the load may now be distributed at random. The existing starting (braking) tension, the normal operating tension, and the elongations implemented by the geometrical conditions of the conveyor should be marked on the belt characteristic curve. In this way, the resulting safety factors may be established for the various operating conditions.

With the help of the safety factor limit $S = 2.5$, more economical belts may be calculated than was previously possible with the former empirical method.

However, the impact stress of the belt at the belt feeding station should be checked when a belt has been calculated with the safety factor $S = 2.5$. The belt impact stress should be within the 20 % safety margin.

Fig. 4: Schematic design of a steelcord belt



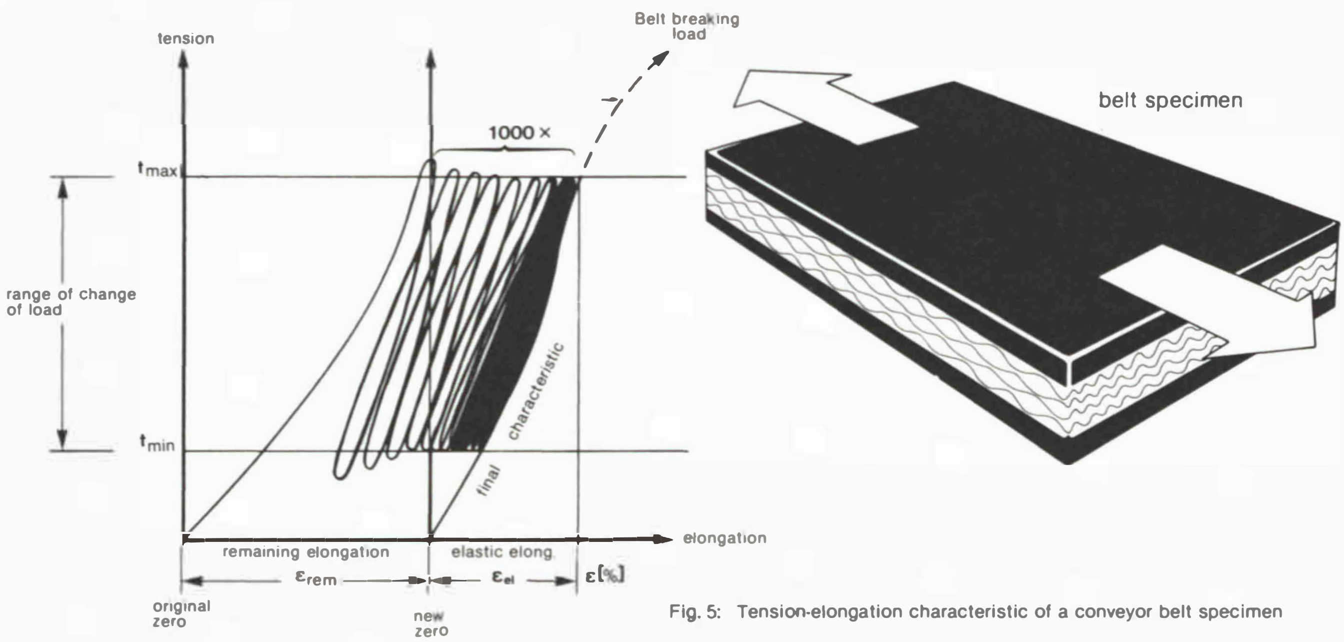


Fig. 5: Tension-elongation characteristic of a conveyor belt specimen

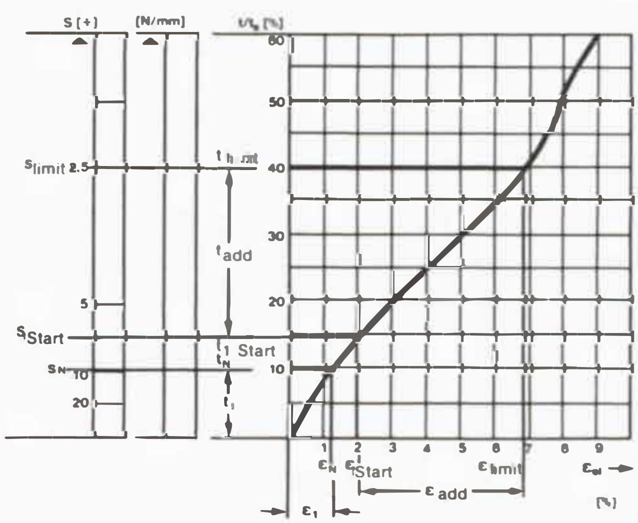


Fig. 6: Tension-elongation characteristic of a conveyor belt

S	safety factor
$S = \frac{t_B}{t}$	
t [N/mm]	lengthwise tension in belt
t_B [N/mm]	belt breaking load
$\frac{t \cdot 100}{t_B}$ [%]	percentage of ratio of belt tension and belt breaking tension
ϵ [%] mm	elongation

There is an empirical formula [4], according to which around 40% of the figures for the belt breaking load, expressed in mkp, correspond to the maximum impact stress of the largest lumps which are likely to damage the belt.

For example:

Breaking load: 3,150 N/mm (St 3150)

40% in mkp: 1,260 mkp = limit of impact stress if, for instance, a lump weighing 630 kg drops from a height of about 2 m onto the belt.

Of course, a safety margin should be allowed for the difference between this figure of height of drop and the actual figure of height of drop at the feeding station of the conveyor. Although this method is not very accurate, experience has shown that it provides good average values drawn from many energy impact measurements (Fig. 7).

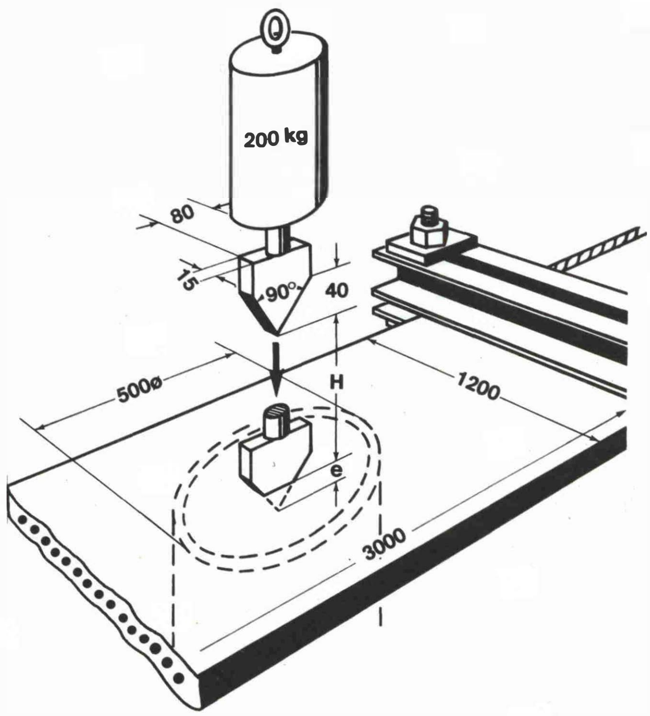


Fig. 7: Testing the impact resistance of a conveyor belt

If a belt is designed with a low safety factor, then the belt, along with its splices, may be loaded more than usual. Therefore, it is important that the design of splices in particular as well as their dynamic resistance have been the object of theoretical and practical research for some time (Fig. 8) [5]. This is also true for the improvements [6]. Furthermore, the quality of craftsmanship is also important in the production of splices [4]. The high standards of splicing technology today enables it to cope with high belt tension without limiting the availability of high tension conveyor belt systems in this respect. However, back to the original topic.

The starting and normal operating tension, impact stress, safety factors, belt types, as well as the splice strength, can now be calculated. The belts may be designed according to this, and, if the calculating methods are applied correctly, these factors should not limit the availability of a conveyor belt considerably.

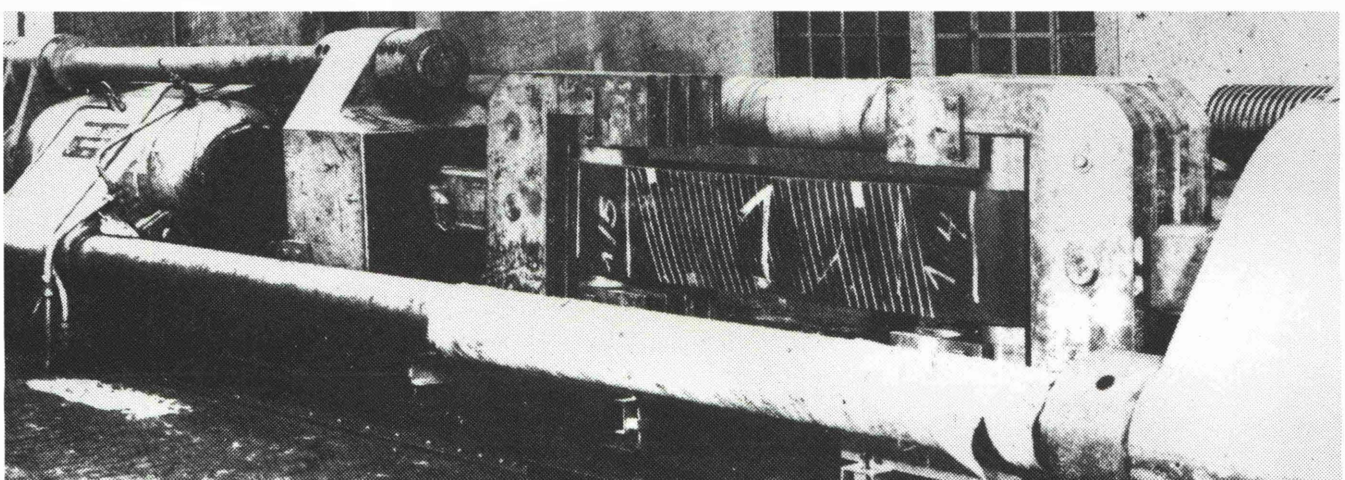
4. Belt Wear and Quality Data

However, normal wear of covers and carcass by the conveyed material, its movement and the movement of the belt over pulleys and idlers, climatic influences, as well as mishandling of the belt, are the actual factors which considerably limit the availability of a conveyor belt. It is here again that the question arises, whether it is possible to make detailed calculations in advance of these influences and thereof calculations about the investment necessary for quality, maintenance and spares of the belt in order to optimise the investment. In most cases, however, there are presently no theoretical or universal methods for their calculation available.

If, for instance, one accepts that in the case of conveyor belts, it is primarily the covers that wear, and if one then tries to determine their thickness in relation to the investment of the belt, one will conclude that it is only empirical and that no calculation method is available. (Fig. 9, Table 1).

The same is true for quality data for belt and covers. Here, data are specified which have been established in the laboratory or through experience (Fig. 10). These data are believed to result in a high availability of the belt, but there is little theoretical proof for this in all cases.

Fig. 8: Testing the splice-strength of a steelcord conveyor belt in 1959



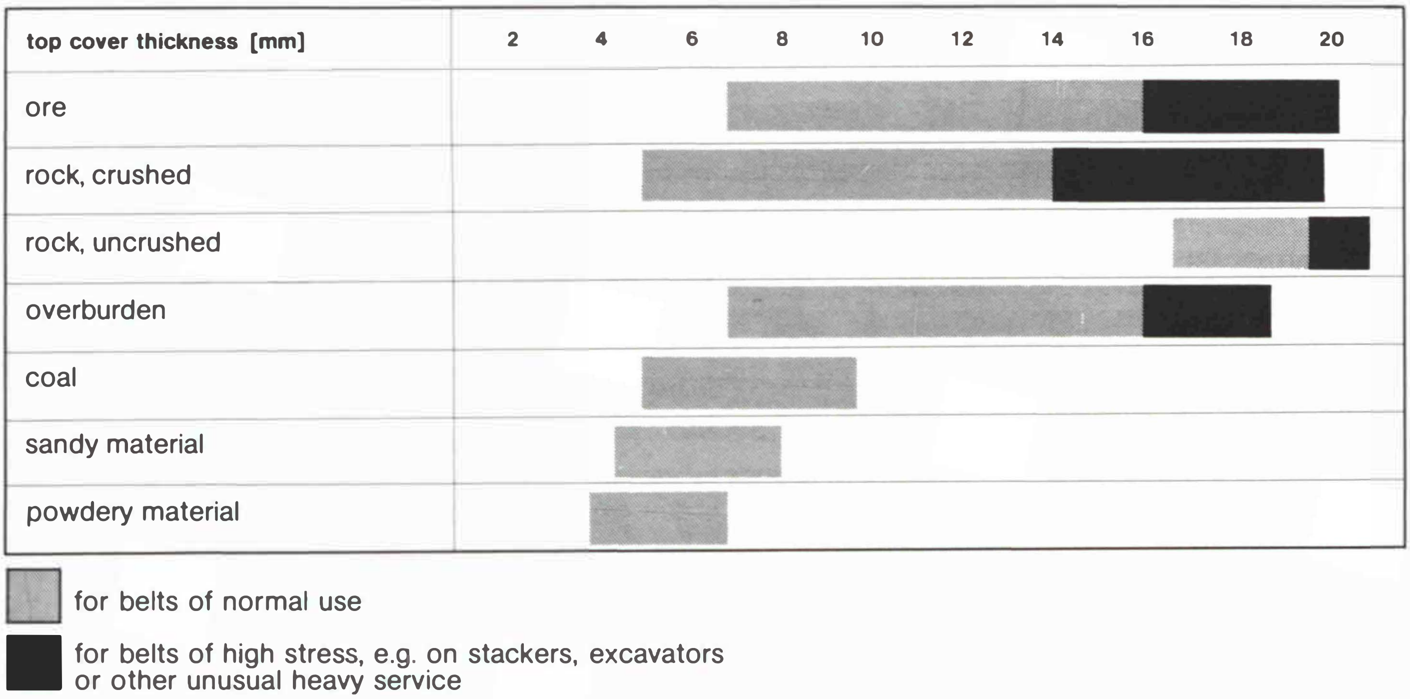


Fig. 9: Usual carrying side cover thickness of steelcord conveyor belts

lump size [mm]	belt cycle T [s] 12	36	60	120	above 240
none abrasive material (soil, round gravel, grain, fibres)					
0 – 50	2.0 mm	1.5 mm	1.5 mm	1.5 mm	1.5 mm
50 – 150	2.5 mm	2.0 mm	2.0 mm	2.0 mm	2.0 mm
above150	4.0 mm	3.5 mm	2.5 mm	2.5 mm	2.5 mm
abrasive material (coal, sharp gravel, slag)					
0 – 50	3.0 mm	2.0 mm	2.0 mm	2.0 mm	2.0 mm
50 – 150	3.5 mm	3.0 mm	2.5 mm	2.5 mm	2.5 mm
above150	4.0 mm	4.0 mm	3.0 mm	3.0 mm	2.5 mm
very abrasive material (coke, ore, overburden with boulders, stones)					
above 150	10.0 mm	8.0 mm	6.0 mm	6.0 mm	6.0 mm

Table 1: Recommendations for cover-thickness according to a conveyor belt handbook

The German standard DIN 22131, for example, quotes only the following quality parameters for steel cord belts (geometric requirements are not mentioned).

— Breaking load of cords.
— Pull-out strength of rubber cords.
— Ditto . . . aged.
— Tensile strength, elongation at break and abrasion of the compound of the cover rubber.
— Separation resistance of layers of rubber.

This, of course, is not enough for a complete control of the service conditions. Big users like mines, therefore, tend to establish their own specifications with considerably more parameters which partly include different values. It is their opinion that these bring about optimal availability of belts: using steel-cord belts again, for example (Table 2). Parallel to these specifications, extensive tests are carried out in laboratories, which means further investments at the manufacturer's factory and on site.

Answers to the following questions still remain a problem: Do the figures of those quality parameters specified correctly represent the stress of the service conditions on site? Does, for instance, a belt with a cover of high tensile strength value last longer than one with a lower value? Or, is a certain value of elongation at the break of the cover rubber of importance? Does the laboratory aging-test really represent climatic influences? If not, what are the actual falsifications? Is the dynamic stress of a belt in mine A the same as in mine

Steel cords:		
Breaking strength of cords		
Elongation of cords		
Pull-out strength of the center strand		
Tensile strength of the single wire		
Coating of cords		
Rubber covers and bonding agents:		
Tensile strength	3310	idem aged
Breaking strength		idem aged
Abrasion		
Hardness		
Tearing strength		
Ozone resistance		
Separating strength between rubber layers		
Pull-out strength osf steel cords, idem aged		
Dynamical pull-out strength of steel cords in the rubber		

Table 2: Excerpts from the steelcord belt specification of "Rheinische Braunkohlenwerke"

B, etc.? And, most importantly, must the highest possible values be required for all technological properties? Is it possible to design a belt more economically?

It is not the task of this paper to make a detailed examination of the quality requirements of conveyor belts in relation to their service conditions and to their economics. Here, the statement should suffice that it has been possible to "breed" high quality conveyor belts with the use of high level quality requirements on the one hand, and the extensive lab-work in the factory and in the mines on the other hand. Such conveyor belts have a high availability; this does not mean, however, that they are optimised in their economy and efficiency. It is a fact, for instance, that all the lab-work and high level quality values for conveyors cost money and that the resulting availability of the belt cannot be compared with this expense.

At present, there are no theoretical methods that are universally applicable; practice is dominated by isolated, empirical methods. This may be explained by the fact that the influences on a belt during its lifetime are so complex that they cannot be theoretically explained by ordinary means.

Nevertheless, there have been continued attempts to do so: One example is provided by the systematic research carried out by the author to determine the wear of eight in-line conveyor belt systems — A to H — of a dam building project. Each of the eight conveyors differed considerably in their service conditions, although they all transported the same material and had the same capacity [7]. A surface stress figure (SSF) was established for this and calculated for each conveyor (Fig. 11).

Parallel to this, the effective degree of wear of the covers was measured subjectively with the help of standard wear patterns. A comparison of both (Fig. 12) showed that the SSF-formula corresponds sufficiently to the wear pattern.

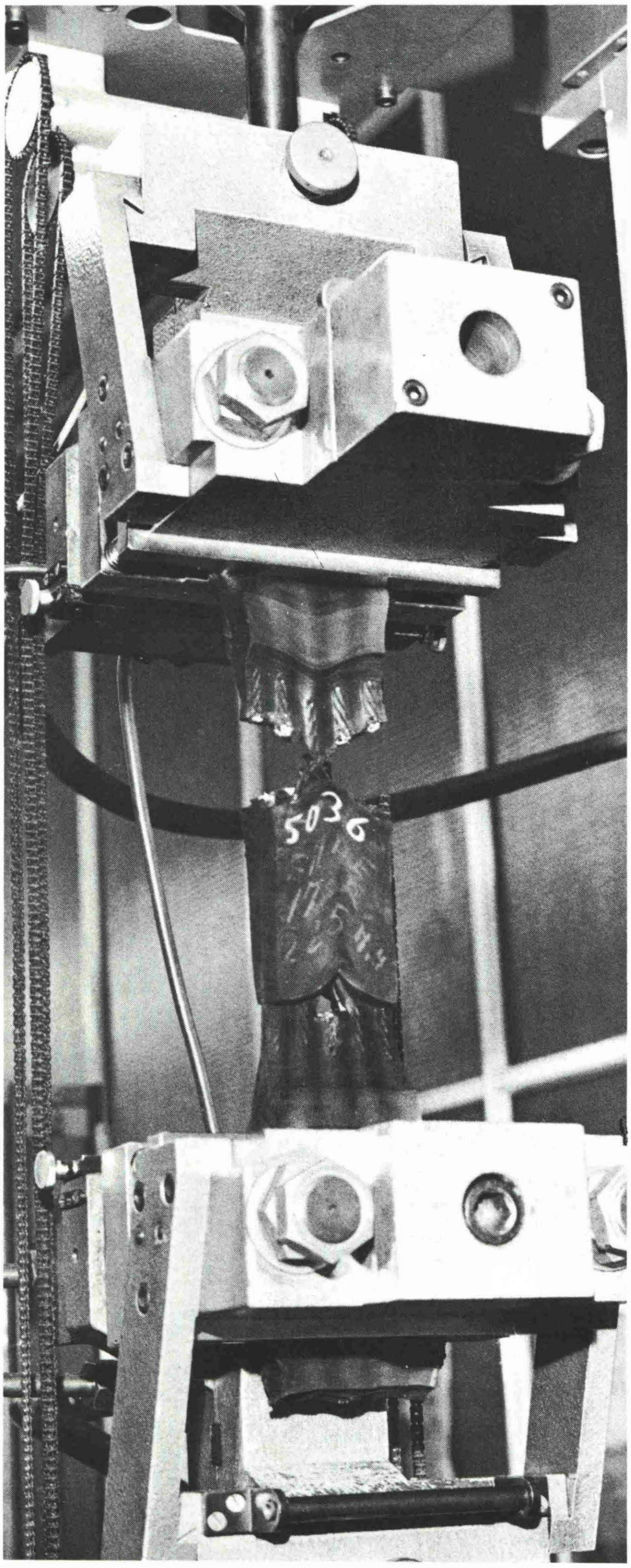


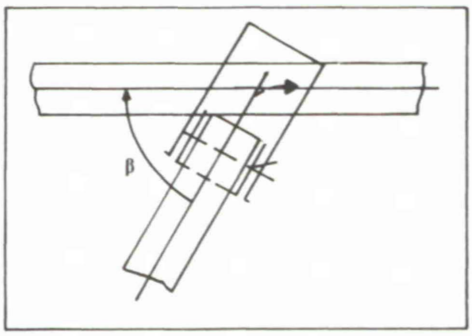
Fig. 10: Lab test of the tensile strength of a steelcord belt

In addition, certain technological properties of the cover compound were varied which were not contained in the specification, however (Fig. 13), and the resulting degree of wear was compared. This provided guidelines for a more economical design of the cover compound properties. It is possible to enter these variations in the SFF-formula.

$$SSF = \frac{h}{k_1 \cdot k_2} \cdot c \frac{l_m \cdot \eta}{2 L_A \cdot B} \left[\frac{m \cdot t}{h \cdot m^2}\right]$$

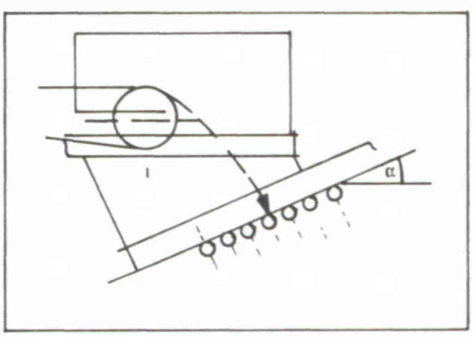
l_m	theoretical capacity (tons per hour)	
η	factor of efficiency of belt conveyor	
B	belt width	
L_A	centre distance	
h	height of drop at feeding station	
c	factor of lump size	
	sand, slurry	c = 0,7
	rolling material 100 mm	0,8
	edged to rolling material 300 mm	1,0
	edged to rolling material over 300 mm	1,4
	sharp edged crushed material 100 mm	2,0
	sharp edged crushed material over 100 mm	2,5
	average of mixed material	a, b, c

$$c = c_a \frac{a\,\%}{100} + c_b \frac{b\,\%}{100} \text{ usw.}$$



horizontal angle of feeding β

β	k_2
0°	1,0
45°	0,95
90°	0,8
> 45°	0,5 and less



vertical angle of feeding α

α	k_1
− 10°	1,5
− 5°	1,2
0°	1,0
+ 8°	0,95
+ 15°	0,90

Fig. 11: Formula for surface stress figure (SSF)

It is significant that in order to apply the formula (Fig. 11), several tables of factors are used which try to catalogue environmental conditions and which even affect the selection of the compound of the belt.

However, it is not yet possible to genuinely predetermine belt wear with this formula. Only the relative wear of belts of different conveyors which all have the same capacity and carry the same material, may be determined in relation to each other.

A further example: The Department of Conveying Technology at the University of Karlsruhe, Fed. Rep. of Germany, has designed and built a conveyor belt wear test stand. A pulley touching the belt carries test lumps of material simulating impacts onto the belt.

To achieve this, the pulley is pressed onto the belt with variable force and it is rotated by the running belt; the belt is braked mechanically and the pressure arising between the lumps and the belt is measured. The lumps as well as all other parameters of the test can be changed within broad limits.

Modern computerised methods such as the use of finite elements to represent the deformation of the cover rubber are applied. By means of this test rig, it is hoped that it will be possible to identify wear patterns of service situations in mines, to analyse these, and to use the results for improving the technology of the belt. With the help of this apparatus, it should be possible to develop a method capable of calculating the investment and resulting availability of belts of all kinds in advance.

5. Statistical Investigations

There are statistical methods as well. These have been used for some time in mines by way of belt card register and systematic failure analysis. Their goal is to optimise quality requirements and to foresee the use of belting in the future.

Even high level organisations are dealing with the problem and are looking for solutions: The Union of German Engineers, VDI, Division of Material Handling and Technology, has published a questionnaire under VDI 3610, which concerns the conveyor belt system and its service conditions. It shows a scheme for the systematic listing of all damage [8], claiming in the preliminary remarks that down-time of conveyors is a heavy economic load for every mine. To reduce the number of stoppages which are not compulsory, it is only possible to watch the technical installations systematically.

The consequences of damage considered by the questionnaire are not included in the present paper.

This VDI-document does not explain, however, how the results of the listing of damage can be linked back to the technological quality requirements or how it may aid the improvement of the availability of conveyor systems, machinery, and belts. This is left up to the comprehension of manufacturers and mines.

The author suggests that an extensive statistical investigation be made which allows the quality requirements to be optimised and which also helps calculate the necessary investment and other factors such as maintenance, etc. Moreover, the availability could be calculated and compared to the total investment in advance, thus making it possible to establish a conveyor belt availability both high and economical at the same time.

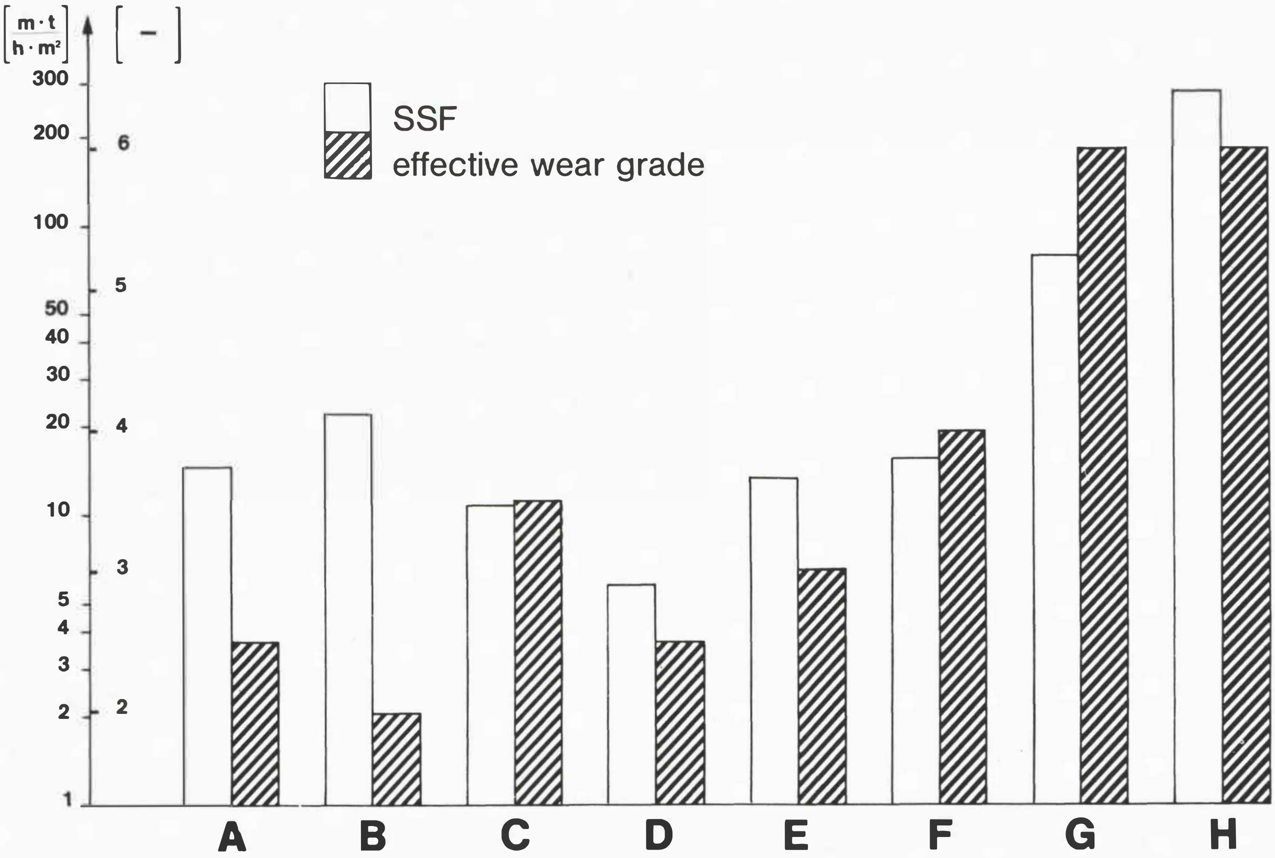


Fig. 12: SSF and effective wear grade

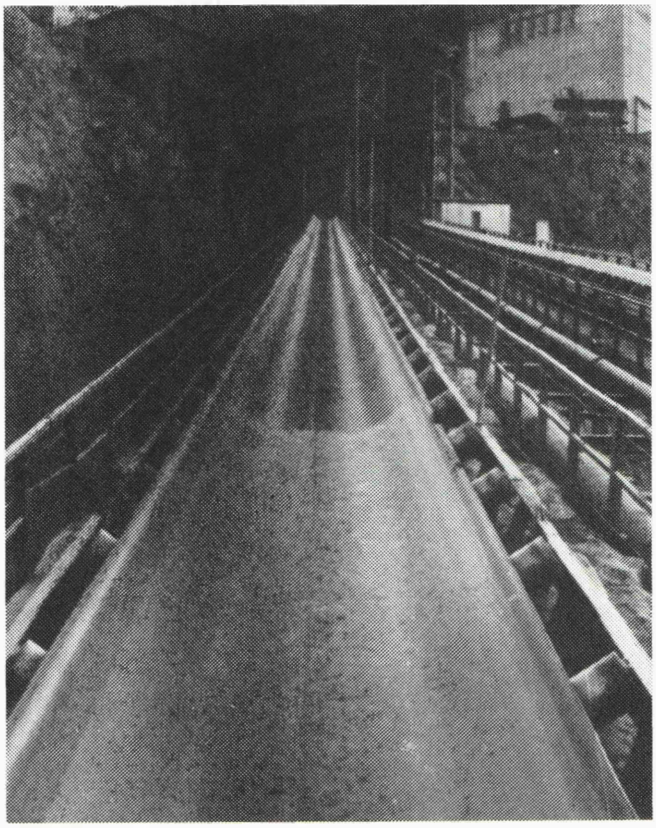


Fig. 13: Result of effective wear of two different test cover compounds (The lab-results did not show such difference.)

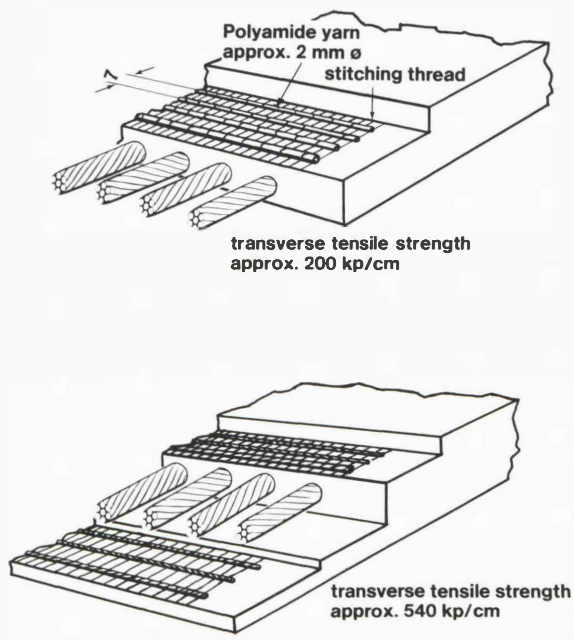


Fig. 14: Steelcord belt with crosswise layers of high tensile textile yarn, top, and top and bottom.

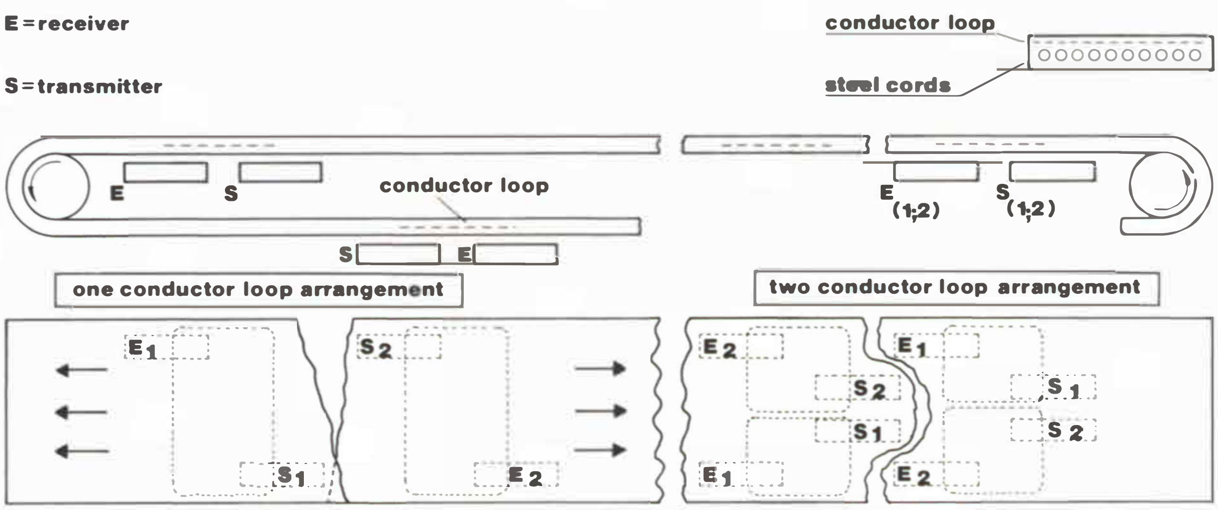
Today, it is technically possible to collect all relevant data on conveyor belt systems and belts from the past and the present with the help of computers and data loggers. This should incorporate all relevant parameters such as investment for purchase, service conditions, quality values, life expectancy data, wear and damages, investment for maintenance, as well as techniques of maintenance, etc.

It is believed that relationships between these parameters may be revealed by the data which are logged. These, in turn, may be converted into formulae. Further tables of factors could be derived from the data thus computed and collected, making it possible to cope with almost all existing service conditions. Formulae and factor tables would then allow complex items such as wear and damages, belt availability and the investment necessary for this to be calculated. Maintenance efforts and replacement needs could be predicted and, further, individually designed quality data could be collected for the belt without the use of a laboratory.

The collection of technical data for conveyor belt systems is not new. Until now, however, this has only been done to improve calculation methods; methods for technical problems such as drive capacities, tension requirements, etc. At present, there is such a research project in progress which is sponsored by the Verband Deutscher Maschinen- und Anlagenbau e.V. (Union of German Machinery and Installation Manufacturers). The Materials Handling Institute of the University of Hannover is doing the measurements. Within the next few years, approximately 30 conveyor systems are to be checked. This project, however, does not address itself to the problems connected with investment for the availability of conveyor belts which are mentioned here.

In order to increase the availability of conveyor belts, certain active and passive methods are being used. One such active method already mentioned is the improvement of belt quality in relation to service condition requirements. This also includes efforts to prevent damage (Fig. 14, 15) and is being carried out systematically mainly by belt manufacturers [9] (Fig. 16). Passive methods include identification (Fig. 17),

Fig. 15: Diagram of the monitoring equipment for the detection of slit steel-cord belts



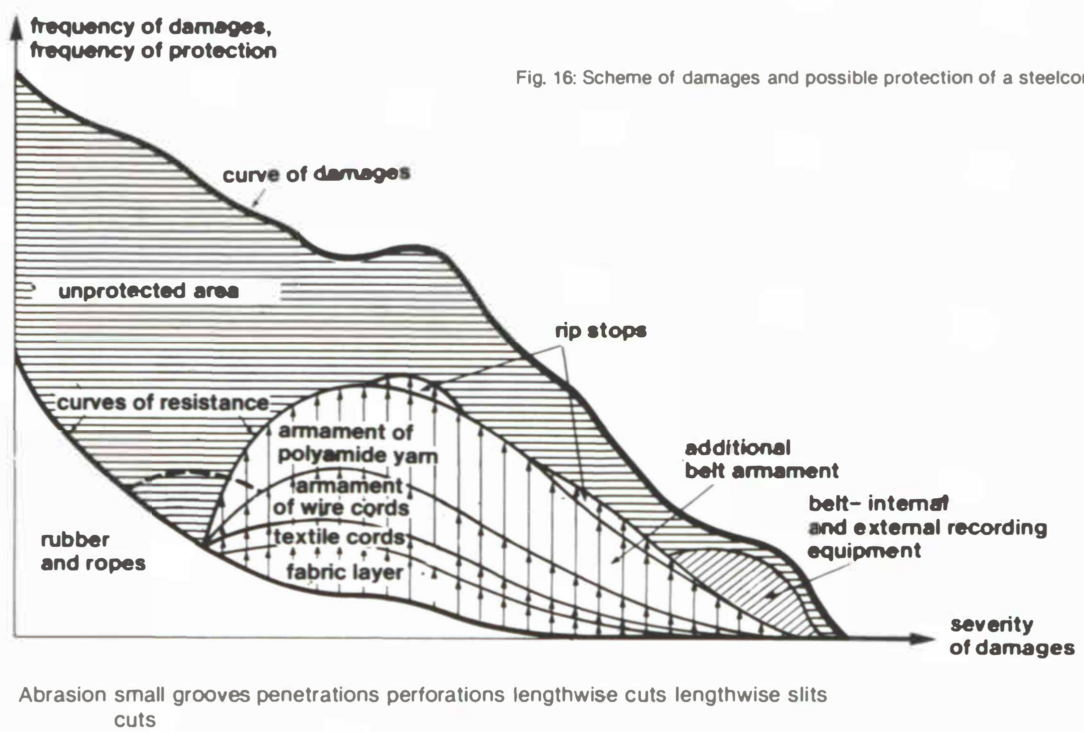


Fig. 16: Scheme of damages and possible protection of a steelcord belt

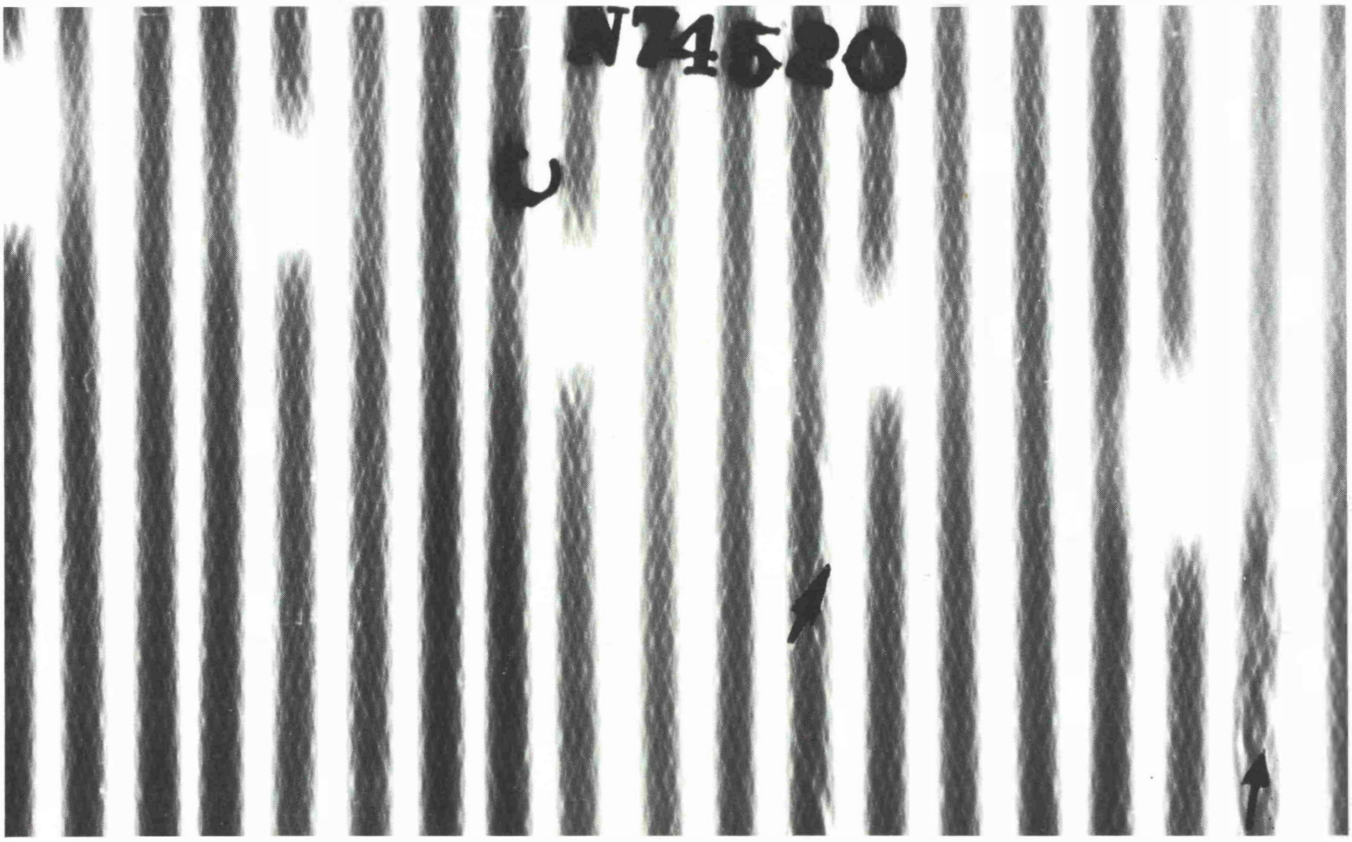


Fig. 17: X-ray picture of section of the splice of a steelcord belt for the Identification of cord-damages

maintenance and repair which are also analysed and then incorporated in the total investment for conveyor belts where possible; this is mostly done in the mines [1, 2, 3, 10] (Fig. 18).

In order to optimise maintenance procedures as such, it should also be possible to use these principles for the extensive statistical investigation mentioned above.

How, for example, should the economical decision regarding the possibilities for the repair of belting be taken? Are the belts to be repaired on site? Or are they to be removed from the site and repaired in a workshop [10]? Does one decide to leave the belt as it is and allow it to run until it wears out completely? Mines have had their own optimised procedures here for some time. However, there is still a need for a complete presentation and evaluation of the problem with the goal of a universal knowledge of technique and investment for belt maintenance that is generally applicable.

6. Psychological Aspects

Finally, the psychological aspect should not be forgotten; namely, that of human behaviour and its effects on the availability of belting. By this, personal attitudes towards the identification and the prevention of damages are meant. This human behaviour cannot, of course, be statistically measured although it is as important as the other factors mentioned. It is known, for example, that workers on the site may be psychologically inhibited when acknowledging the reasons for semi-serious damages because they are afraid of facing personal consequences. A lack of personal concern, on the other hand, may also have a negative effect on conveyor belts as well.

It is precisely in this area of individual quality control and damage prevention that an interesting development is taking place.

A new and internationally successful method at the workshop level is attracting attention. It is called the Quality Control Circles (QCCs) method [11].

The basic idea of the Circle is to provide training for up to a dozen volunteer workers in the systematics of problem analysis techniques. They receive time off from their work to attend ninety minutes of class once a week for four weeks. The circle members are permitted to choose the problem they wish to tackle and, if possible, to implement solutions and monitor results. The leader of a group reports directly to a senior manager with top-level responsibility for the programme. The group members are allowed to meet regularly during normal working hours. As reported, the group members are highly motivated by their own responsibility and success as well as by the possibility of being able to report directly to top management levels.

The QCCs have already been successful in many areas. The system originated in the USA and was successfully modified in Japan. The main tools constituting this problem analysis technique, which may also be easily adapted to conveyor belt maintenance, are the following:

Brainstorming; check sheet, Pareto* chart (Fig. 19); cause and effect diagram; histograms (compare Fig. 12); scatter diagrams; graph and control chart; stratification, etc.. International training consultants may introduce the QCC techniques.

*) The Italian sociologist who graphically showed that 80 % of the wealth of a nation lies in the pockets of 20 % of its people. Transferred to this paper: 80 % of all damage is being caused by only 20 % of all causes. The Pareto method allows one to find out central points of trouble.

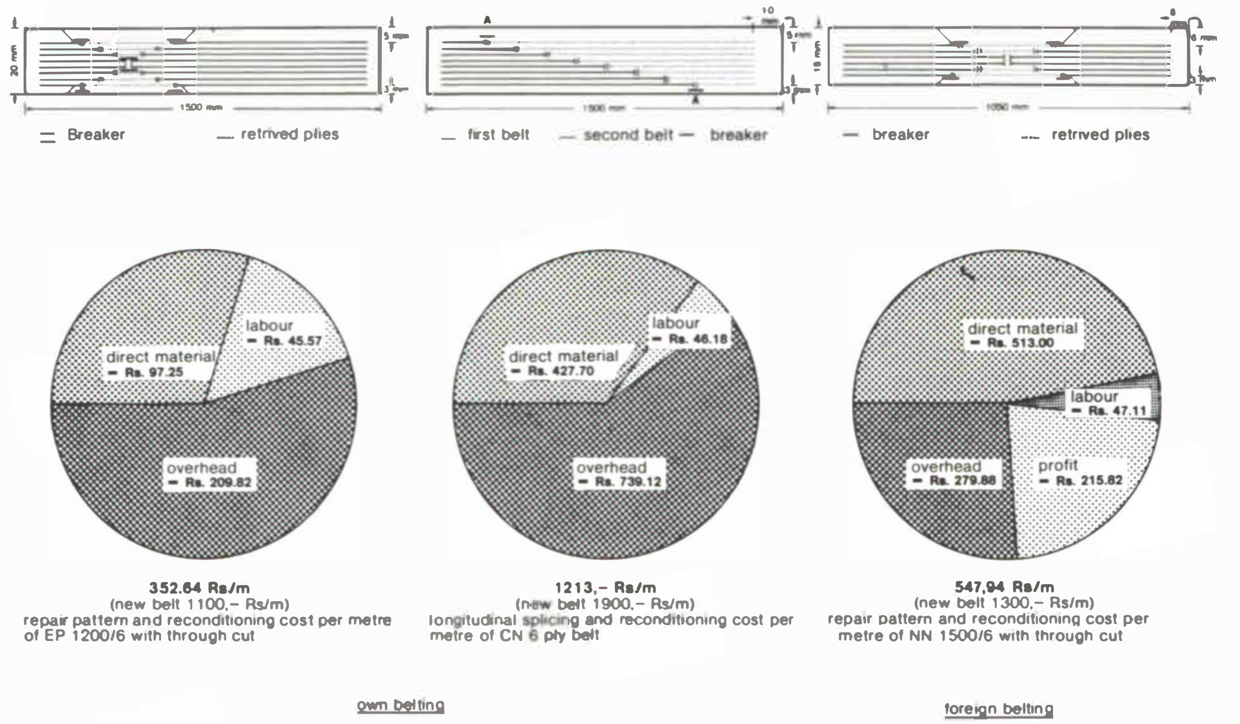


Fig. 18: Example of analysis of repair procedure and repair costs of fabric belting (repair workshop of Neyveli Lignite Corporation Ltd., India)

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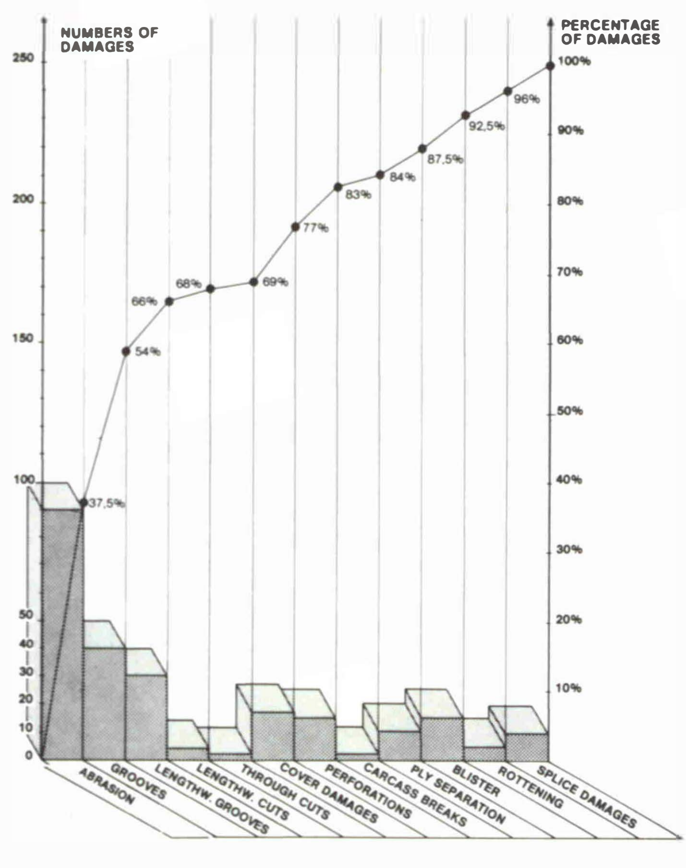

Fig. 19: Pareto Diagram