THE NEXT GENERATION LOW LOSS CONVEYOR BELTS

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ABSTRACT

Low loss rubber compounds were introduced over fifteen years ago. Since then the rubber compounds evolved further and what used to be a low loss compound fifteen years ago is basically standard quality today. For conveyor belt manufacturers it is therefore increasingly difficult to stay at the vanguard of rubber technology and to retain the option of offering a real low loss conveyor belt. To achieve a further significant reduction of the power consumption in the current low loss belt conveyor, the weight of the belt needs to be significantly decreased and the properties of the rubber compound need to be changed drastically. This paper discusses options for the next generation low loss conveyor belts. It also discusses the effects of applying next generation low loss conveyor belts in an existing South African project.

1. INTRODUCTION

Depending on the geometry of a belt conveyor, it can be said that for a long overland belt conveyor with a relatively flat profile, about 60% to 70% of the required drive power is consumed by the indentation rolling resistance [1]-[2]. The indentation rolling resistance is caused by the visco-elastic nature of the rubber covers of the conveyor belt [2]. In general, the indentation rolling resistance force F_i is defined by [2]:

$$F_i = CF_z^{n_z} h^{n_h} D^{-n_D} v^{n_v} K_N^{-n_K} T^{n_T} \qquad (1)$$

Where C is a constant, F_z the vertical force applied on an idler roll by the weight of the belt and the bulk solid material on the belt, D the diameter of the idler roll, v the belt speed, K_N the nominal per cent belt load and T the temperature. The coefficients n_i are introduced in [2]. The coefficients n_Z, n_h, and n_D are constants and are respectively 4/3, 1/3, and 2/3. The other three coefficients are not constant. The coefficient n_K depends on the roll diameter D. The coefficients n_v and n_T depend on the deformation rate of the rubber and the storage modulus of the rubber belt covers. In essence, the six parameters of equation 1 provide options for the reduction of the indentation rolling resistance and thus the overall energy consumption of a belt conveyor.

In order to reduce the energy consumption of an existing belt conveyor a number of practical measures can be taken:

1. Change conveyor components (affects the parameters D, K_n)
2. Change operational parameters (affects the parameters v, F_z)
3. Change belt properties (affects the parameters h, T)

Conveyor components

The number of options to lower the indentation rolling resistance by making changes to belt conveyor components, excluding the belt, are limited. The only really effective measure is to use idler rolls with a larger diameter than normal. This affects the indentation rolling resistance both directly (via D) as well as indirectly (via K_n). From equation 1 it can be seen that, if for example, the roll diameter is doubled, the indentation rolling resistance decreases by a factor of at least $2^{1/3}$. Another option to decrease the energy consumption of a belt conveyor is the application of more energy efficient drives.

Operational parameters

Possible changes in operational parameters in reality are also limited. A belt conveyor is designed to safely and reliably transport a certain amount of bulk solid material over a certain distance. Normally it is not overdesigned. Sometimes the actual volumetric capacity of a belt conveyor is not fully utilised, due to either operational circumstances or built-in upgrade possibilities. In that case the belt speed v can be adjusted so that the volumetric capacity of the conveyor stays at the design capacity. This can reduce the power consumption of the belt conveyor significantly as discussed in [3]. In terms of equation 1, decreasing the belt speed to increase the volumetric utilisation affects the vertical load F_z as well as the belt speed v. The indentation rolling resistance increases with a decrease of the belt speed caused by the increase of the vertical belt load. The required power however, which is the product of the resistance force and the belt speed, decreases. Other operational measures can be a more frequent shut-down of the conveyor after it has been run empty. In practice, this may not be desirable because it increases the logistic complexity of the operation.

Belt properties

The most effective way to accomplish energy savings is by changing the conveyor belt itself. Three main options are available.

From equation 1 it can be learned that firstly, the thickness of the belt cover in contact with the idler rolls plays an important part in the indentation rolling resistance. Although the effects on a fabric reinforced belt and a steel cord reinforced belt differ, in general the indentation rolling resistance decreases with a decreasing belt cover thickness. Expected wear of the belt cover on the carry and the return side determines the required cover thicknesses. Therefore options to reduce the indentation rolling resistance by decreasing the cover thickness are limited. In practice, a belt turnover can be used to turn the belt so that the normally thinner, bottom cover also supports the belt in the return strand. It should be noted that a passage of the belt through a belt turnover also requires power so that the application of belt turnovers to reduce the energy consumption of the overall conveyor, requires a certain minimum conveyor length.

The second main option is to reduce the belt weight. The belt weight is roughly made up from the weight of the belt carcass and covers. Since the belt covers have a certain required minimum thickness there is not much to gain in terms of weight by changing the belt covers unless a rubber compound can be used with a much lower density than the rubbers used today. Decreasing the density of the cover rubber will however, seriously affect the wear properties of the covers. A more practical option is to change the carcass. Most long overland belt conveyors and large scale systems utilise steel cord reinforcement. If the steel cords are replaced by a much lighter material like aramid then the belt weight reduces substantially which leads to significant energy savings.

The third main option is to change the recipe of the rubber compound used for the belt covers to reduce the effect of the visco-elasticity of the belt. The more elastic the rubber behaves, the lower the indentation rolling resistance. This is not new, most existing low loss rubbers are based on a change in the recipe of the rubber compound. Three main options are possible. Firstly, an additive to the recipe, like aramid, can be used. Secondly, an ingredient like the filler material can be exchanged for an alternative that increases the elasticity of the rubber. Thirdly, another rubber type can be used.

This paper discusses the effects of using aramid in a conveyor belt, both as a carcass as well as an additive to the rubber compound. In addition, it discusses the effect of changing a rubber type in the compound.

2. APPLICATION OF ARAMID

Aramid is a short form for 'aromatic polyamide'. Aramid fibres are man-made high-performance fibres. Their molecules are characterised by relatively rigid polymer chains, linked by strong hydrogen bonds that transfer mechanical stress (Figure 1). This permits the use of chains of relatively low molecular weight. Aromatic polyamides were first applied commercially as meta-aramid fibres in the early 1960's, and para-aramid fibres were subsequently developed in the 1960's and 1970's [4].

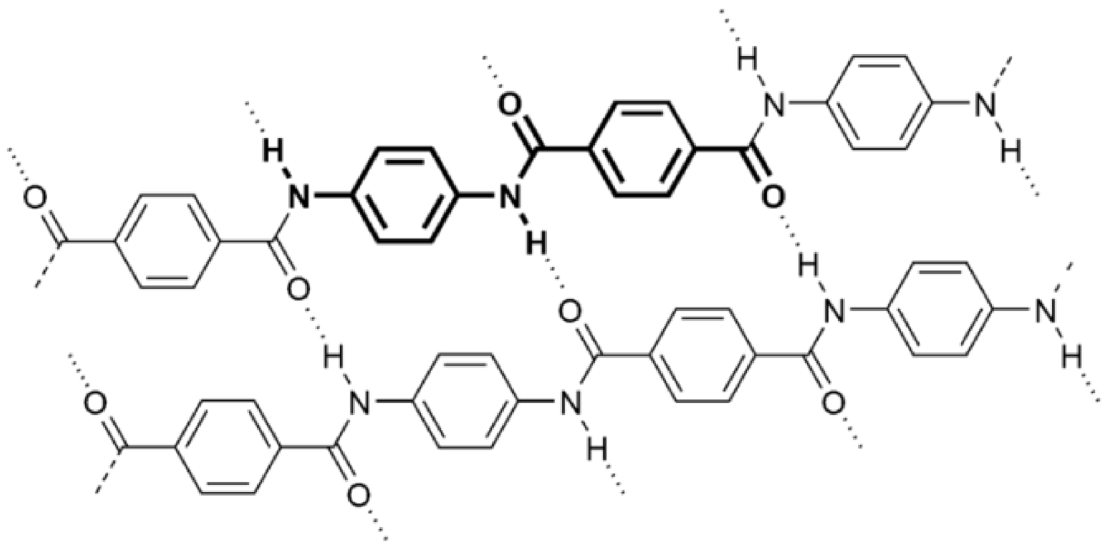

Figure 1. Para-aramid structure.

Two products based on aramid have been developed in the Netherlands that can be used in conveyor belts: Twaron® and Sulfron® [5] and [6]. Twaron® is a very strong, light para-aramid fibre (poly-paraphenylene terephthalamide. It has a high modulus, is thermally stable, and highly impact and chemical resistant. Sulfron®, a modified Twaron aramid, improves the properties of sulphur- and peroxide- cured rubber compounds. It reduces hysteresis, heat build-up and abrasion of carbon black-filled compounds, while improving flexibility, tear and fatigue properties. Sulfron is a compounding ingredient that can be used to reduce the hysteresis of carbon black-filled compounds and of compounds containing both carbon black and silica. During mixing of Sulfron at elevated temperatures, intermediate reaction products are formed that interact with the carbon black particles and thereby reduce the filler-filler interaction (improving the Payne effect) resulting in a compound with reduced frictional energy and thus improved hysteresis properties.

The application of aramid in belt conveyors is not new. At the beginning of the 1990's, aramid had already been applied in belt conveyors as reinforcement. Recently however, aramid has also been used as an additive in the compound of the rubber used for the belt covers. Together the two applications are very promising in creating opportunities for energy savings in belt conveyors. The question is whether or not conveyor belts utilising aramid additives and an aramid carcass can be called the new generation low loss conveyor belts.

2.1 Belt Carcass

Aramid is a high strength fibre with tensile properties close to steel. At the same strength, aramid is five times lighter than steel and three times lighter than polyester (Figure 2). This means that an aramid reinforced conveyor belt weighs considerably less than one with a conventional reinforcement, especially if compared with steel [5]-[6].

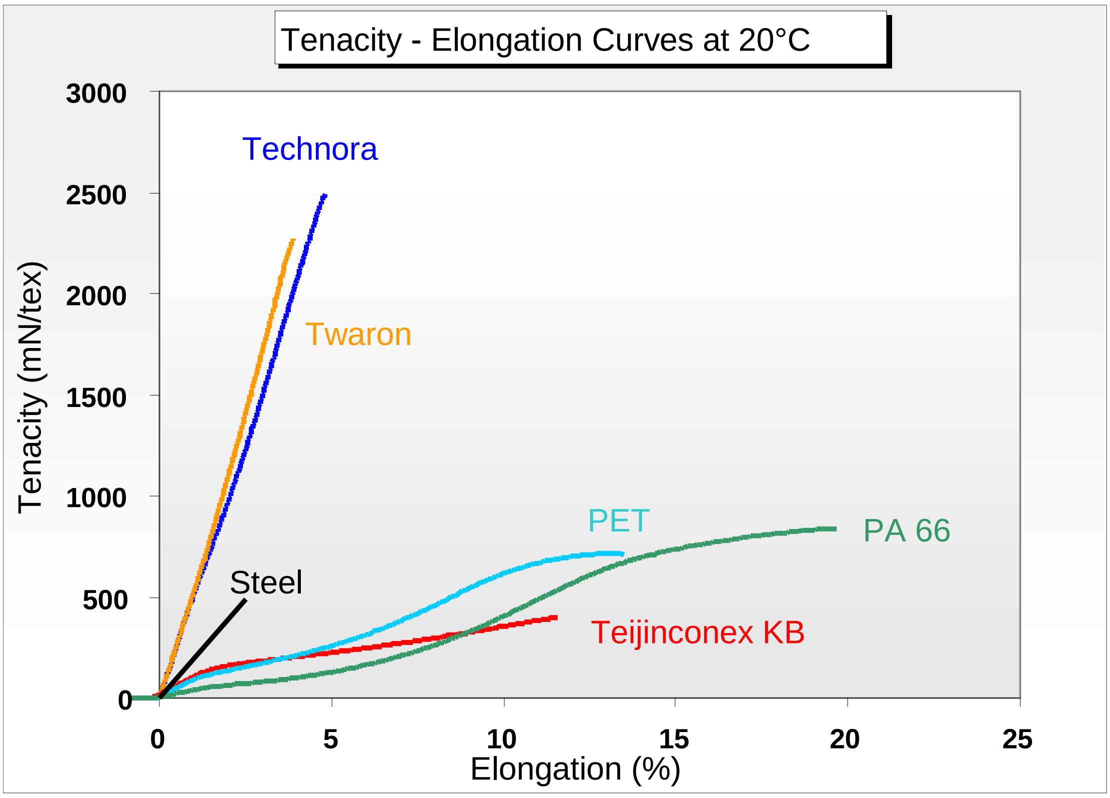

Figure 2. Tenacity, elongation of aramid, steel and polyester [5].

Most long overland and heavy duty conveyor belts are reinforced with steel cords. As an alternative, an aramid fabric can be used, typically in the shape of a straight warp fabric or cord fabric. In these fabrics the aramid is oriented longitudinally and straight for optimal strength and modulus, as schematically represented in Figure 3. Another idea is to use aramid in the form of cables, like a steel cord belt. This however, has not been developed yet.

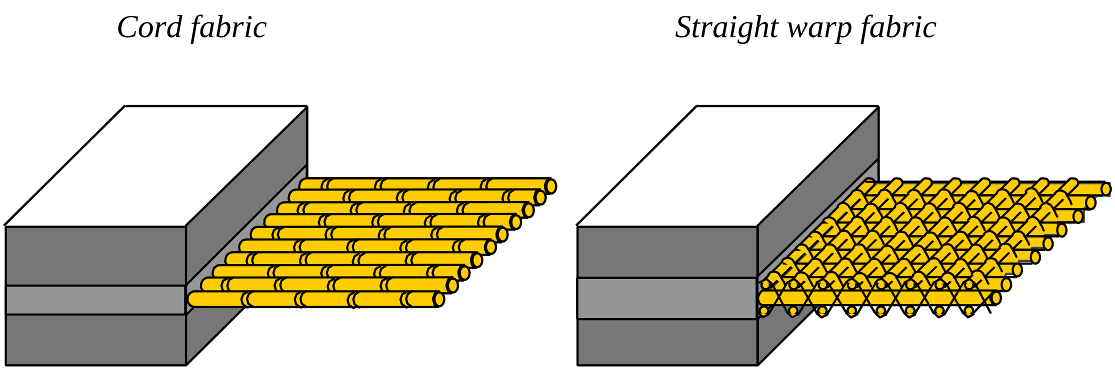

Figure 3. Cord versus straight warp fabric.

Conventional fabric reinforcement has a low elasticity modulus and requires a long take-up length. As aramid is a high modulus fibre, belt elongation is low and close to that of steel belts (Figure 4).

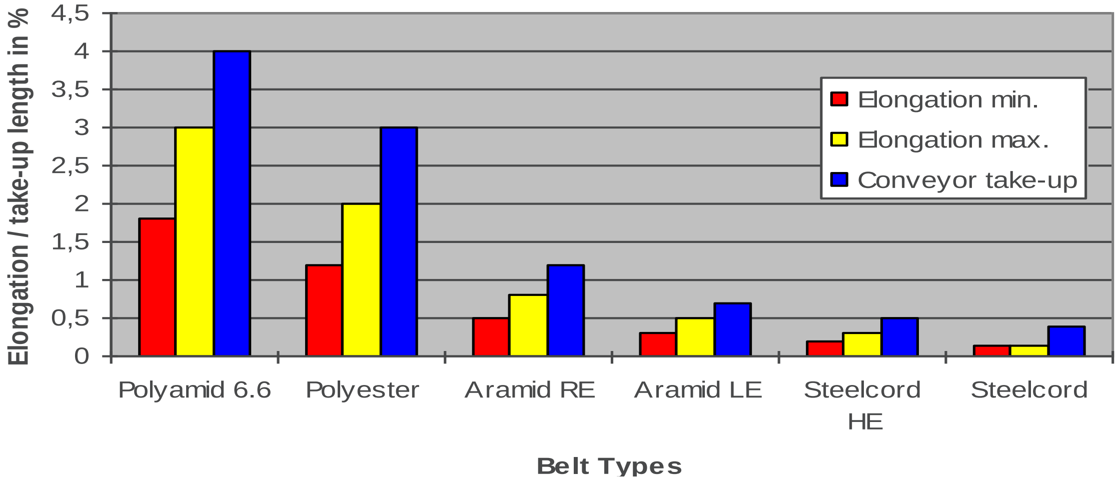

Figure 4. Belt elongation and recommended take-up in percentage of centre distance with different reinforcement materials [5].

2.2 Belt Covers

Sulfron is a new aramid-based rubber ingredient that reduces hysteresis. The effect is that the rubber compound that has Sulfron as an additive behaves more elastically. It is to be expected that this reduces the indentation rolling resistance [2]. Sulfron is pellet shaped and can be mixed into rubber compounds at low loadings of typically around 2 phr (Figure 5). Phr stands for parts per hundredth rubber. If a compounds requires 2 phr of a certain ingredient then 100 g rubber requires 2 g of the additive. The properties of rubbers with and without addition of Sulfron are discussed in the next section.

Figure 5. Sulfron pellets (actual size ca. 6 mm) [5].

3. RUBBER PROPERTIES

Typically, the rubber compounds that are used in conveyor belting for long overland conveyor systems have about 40% of SBR rubber (Styrene-Butadiene-Rubber) and 60% of NR rubber (Natural Rubber). The exact ratio depends, among other factors, on the price of the different rubbers on the world market. The properties of a 60% NR and 40% SBR rubber compound do not differ substantially from an 80% NR and 20% SBR rubber compound in terms of visco-elastic properties. To enable the investigation into the effect of applying Sulfron in the belt bottom cover compound and changing from using SBR rubber to BR (Butadiene-Rubber), six rubbers were prepared (Table 1). Rubber 1 can be considered as the standard modern rubber used in long overland belt conveyors. The rubbers 2 to 6 are variants using 1,5 or 2 phr Sulfron and/or BR instead of SBR. In general BR is known to increase the elasticity of a rubber compound more than SBR. It is therefore to be expected that the NR/BR rubbers perform better in terms of the indentation rolling resistance than the SBR/NR rubbers.

	Rubber 1	**Rubber 2**	**Rubber 3**	**Rubber 4**	**Rubber 5**	**Rubber 6**
NR (SMR10) [%]	80%	80%	80%	80%	80%	80%
SBR (Buna SB 1500) [%]	20%	20%	20%	0%	0%	0%
BR (Buna cis 132) [%]	0%	0%	0%	20%	20%	20%
S 3001 [phr]	0,0	1,5	2,0	0,0	1,5	2,0
N339 type	50	50	50	50	50	50
Nytex 840	5	5	5	8	8	8
Zinc oxide	3	3	3	3	3	3
Stearic acid	1,5	1,5	1,5	1	1	1
Sunolite 240	2,5	2,05	1,75	2,5	2,05	1,75
6 PPD	1,5	1,5	1,5	1	1	1
TMQ	1	1	1	1	1	1
CBS	1,5	1,5	1,5	1,5	1,5	1,5
Sulfur	2,5	2,5	2,5	2,5	2,5	2,5

Table 1. Definition of the six used rubber compounds.

In all six rubbers, the dynamic mechanic parameters have been determined according to the procedure described in [7]. In order to get a first impression of the performance of the six rubbers, the maximum rolling coefficient (MRC) has been calculated. The MRC is a parameter that is directly proportional to the indentation rolling resistance. In literature a number of expressions of the MRC can be found. Here, the MRC using the Jonker's theory is used [8]. The MRC can be expressed as follows:

$$MRC = \frac{0.5\pi \tan\delta}{E'^{1/3}} \left[\frac{(\pi+2\delta)\cos\delta}{4\sqrt{1+\sin\delta}}\right]^{4/3} \qquad (2)$$

where E' is the storage modulus of the rubber and tanδ the loss factor. Figure 6 shows the MRC for the six rubbers. Please note that the rubbers have been designed for application where ambient temperatures are relatively normal . The compounds are not fit for application in belting that has to be used in arctic ambient conditions. Figure 2 shows that the application of Sulfron in the rubber has a significant effect, reducing the MRC of the rubber. In addition, changing from SBR to BR further reduces the MRC.

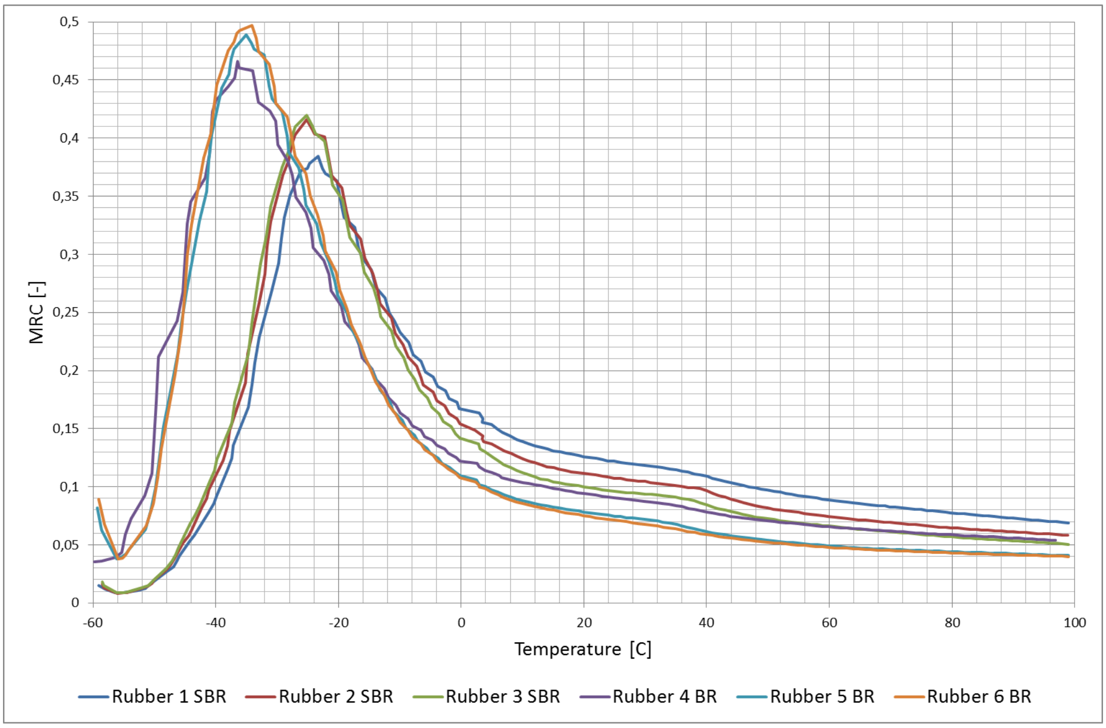

Figure 6. MRC values for the six rubber types.

To further access the applicability of the five new rubbers in belt conveyor cover compounds, the hardness and the abrasion characteristics were tested and compared against the properties of the basis rubber 1. Figure 7 shows that the rubber hardness, expressed in Shore A, hardly changes between the rubbers. Figure 8 shows that the abrasion characteristics also do not change dramatically. All six rubbers classify as at least DIN-X type rubber which is very common for rubber compounds used in the covers of conveyor belting of long overland belt conveyors.

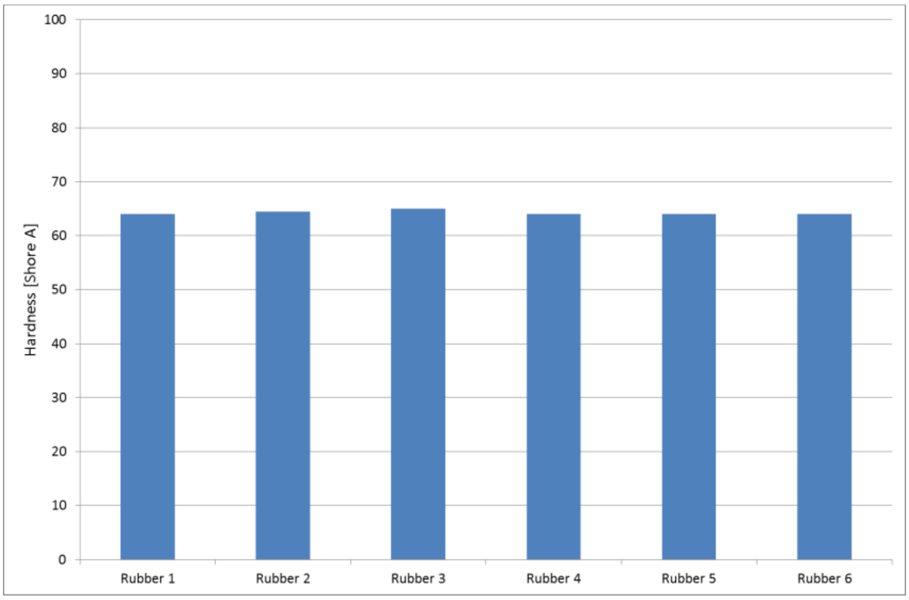

Figure 7. Hardness values for the six rubber types.

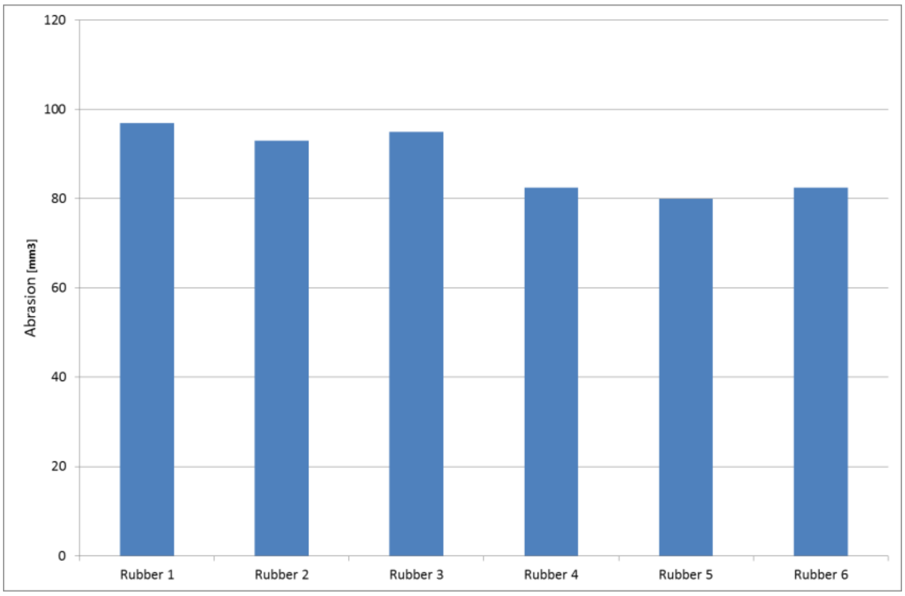

Figure 8. Abrasion values for the six rubber types (tested in accordance with DIN 53516).

4. CASE STUDY

In order to assess the potential of the application of aramid and BR instead of SBR in real belt conveyors in terms of energy, and thus costs and savings, a case study was performed. For this study the power requirements of the, at the time, new overland conveyor system at Optimum Collieries were reviewed. The Optimum Collieries are located in the Mpumalanga province, Republic of South Africa. Some typical aspects of the Optimum project have already been discussed in [7].

4.1 Project Description

The Optimum overland system consists of five belt conveyors: four, at the time, new belt conveyors KW-01, KW-02, KW-03 and KW-05, and one upgraded belt conveyor S-3. Here, only the new KW conveyors are discussed, see Figure 9 for an impression of the system.

The conveyor belts that were originally utilised for the KW belt conveyors had covers with a 60%NR/40%SBR rubber. The properties of a 60% NR and 40% SBR rubber compound do not differ substantially from an 80% NR and 20% SBR rubber compound in terms of visco-elastic properties. Therefore rubber 1 is used in the case study as basic rubber that behaves similarly to the rubber used in the covers of the originally installed conveyor belting.

Table 2 shows the data of the original KW belt conveyors of the Optimum overland system. In Tables 3 and 4, the belt masses are calculated for the original belts and, as an alternative, the same conveyor belts using a Twaron carcass are calculated. The masses listed in these tables have been used for the analyses. The ST code used in the tables stands for a steel cord carcass, the D code stands for a Twaron carcass. In the case study the effect of using six different rubbers and two different carcasses are analysed. Therefore the effects of twelve options are calculated.

Figure 9. Overland conveyor KW-05 looking towards the head of the conveyor.

Overview of the new Optimum belt conveyors				
Belt conveyor	KW-01	KW-02	KW-03	KW-05
Capacity [MTPH]	2.200	2.200	1.800	1.800
Installed power [kW]	1.890	945	945	945
Belt speed [m/s]	5,75	5,75	5,75	5,75
Belt width [mm]	1.200	1.200	1.050	1.050
Belt rating [-]	ST 1400	ST 1400	ST 900	ST 900
Belt covers [mm]	6+4	6+4	6+4	6+4
Rubber compound	60%NR, 40% SBR	60%NR, 40% SBR	60%NR, 40% SBR	60%NR, 40% SBR
Belt mass [kg/m]	31,7	31,7	22,6	22,6
Length [m]	5.280	2.700	3.720	3.304
Elevation change [m]	26,5	3,3	-13,4	-5,05

Table 2. Data of the four new Optimum belt conveyors.

ST 1400 - 1200 mm	Thickness [mm]	Density [kg/m3]	Mass [kg/m]
Top cover	6,0	1.150	8,3
Adhesion layer	1,0	1.150	1,4
Carcass	1,0	7.850	9,6
Filling	4,0	1.150	5,5
Adhesion layer	1,0	1.150	1,4
Bottom cover	4,0	1.150	5,5
Total	17,0		**31,7**
D 1400 - 1200 mm	Thickness [mm]	Density [kg/m3]	Mass [kg/m]
Top cover	6,0	1.150	8,3
Adhesion layer	1,0	1.150	1,4
Carcass	1,3	1.450	2,3
Adhesion layer	1,0	1.150	1,4
Bottom cover	4,0	1.150	5,5
Total	13,3		**18,8**

Table 3. Calculation of belt mass of the 1.400 N/mm rated belts with belt width of 1.200 mm.

ST 900 - 1050 mm	Thickness [mm]	Density [kg/m3]	Mass [kg/m]
Top cover	6,0	1.150	7,2
Adhesion layer	1,0	1.150	1,2
Carcass	0,6	7.850	4,9
Filling	2,6	1.150	3,1
Adhesion layer	1,0	1.150	1,2
Bottom cover	4,0	1.150	4,8
Total	15,2		**22,6**
D 900 - 1050 mm	Thickness [mm]	Density [kg/m3]	Mass [kg/m]
Top cover	6,0	1.150	7,2
Adhesion layer	1,0	1.150	1,2
Carcass	1,0	1.450	1,4
Adhesion layer	1,0	1.150	1,2
Bottom cover	4,0	1.150	4,8
Total	13,0		**15,9**

Table 4. Calculation of belt mass of the 900 N/mm rated belts with a belt width of 1.050 mm.

4.2 **Calculation Results**

The calculations performed in the case study are based on the original design calculations that were done in 2002/2003 by the author. The original design calculations showed the required drive power numbers of the belt conveyors, the tension levels, starting and stopping procedures etc. In order to facilitate a study into the effects of using a Sulfron additive, BR instead of SBR rubber, and a change in carcass, the original design calculations were repeated with the belt conveyor data listed in Tables 2 to 4, using the parameters of rubber 1 under summer conditions in Mpumalanga (35 degrees centigrade). The calculations with the rubber 1 data yielded the basis power data. In the rest of this paper only the required power numbers will be discussed since the focus is on the question of whether or not the application of aramid leads to the next generation low loss belt conveyors.

Tables 5, 6, 7 and 8 list the required drive power numbers of the overland conveyors KW-01, KW-02, KW-03 and KW-05 respectively. The first column shows the rubber type used. The exact compound of the rubbers is given in the second column. The third column lists the carcass type used. The fourth and the fifth columns list the drive power requirement of the belt conveyors when fully loaded and when empty. The last two columns show the possible power savings related to the base case: a conveyor belt with rubber 1 in the bottom cover and a steel cord carcass.

Summary of calculation results for belt conveyor KW-01 @ 35 degrees C						
			Power requirement [kW]		Power savings [%]	
Rubber type		**Carcass type**	**Fully loaded**	**Empty**	**Fully loaded**	**Empty**
Rubber 1	NR/SBR	Steel cord	1.497,8	505,2	0,0%	0,0%
Rubber 2	NR/SBR with 1.5phr Sulfron 3001	Steel cord	1.393,4	465,6	7,0%	7,8%
Rubber 3	NR/SBR with 2.0phr Sulfron 3001	Steel cord	1.321,8	438,4	11,8%	13,2%
Rubber 4	NR/BR	Steel cord	1.277,2	421,5	14,7%	16,6%
Rubber 5	NR/BR with 1.5phr Sulfron 3001	Steel cord	1.126,1	364,1	24,8%	27,9%
Rubber 6	NR/BR with 2.0phr Sulfron 3001	Steel cord	1.094,6	352,1	26,9%	30,3%
Rubber 1	NR/SBR	Twaron	1.266,0	294,7	15,5%	41,7%
Rubber 2	NR/SBR with 1.5phr Sulfron 3001	Twaron	1.179,8	271,6	21,2%	46,2%
Rubber 3	NR/SBR with 2.0phr Sulfron 3001	Twaron	1.120,6	255,7	25,2%	49,4%
Rubber 4	NR/BR	Twaron	1.083,9	245,8	27,6%	51,3%
Rubber 5	NR/BR with 1.5phr Sulfron 3001	Twaron	959,1	212,4	36,0%	58,0%
Rubber 6	NR/BR with 2.0phr Sulfron 3001	Twaron	933,0	205,4	37,7%	59,3%

Table 5. Calculation results for overland conveyor KW-01.

Summary of calculation results for belt conveyor KW-02 @ 35 degrees C						
			Power requirement [kW]		Power savings [%]	
Rubber type		**Carcass type**	**Fully loaded**	**Empty**	**Fully loaded**	**Empty**
Rubber 1	NR/SBR	Steel cord	508,6	194,8	0,0%	0,0%
Rubber 2	NR/SBR with 1.5phr Sulfron 3001	Steel cord	471,2	179,9	7,4%	7,7%
Rubber 3	NR/SBR with 2.0phr Sulfron 3001	Steel cord	445,5	169,6	12,4%	12,9%
Rubber 4	NR/BR	Steel cord	429,6	163,3	15,5%	16,2%
Rubber 5	NR/BR with 1.5phr Sulfron 3001	Steel cord	375,5	141,6	26,2%	27,3%
Rubber 6	NR/BR with 2.0phr Sulfron 3001	Steel cord	364,2	137,1	28,4%	29,6%
Rubber 1	NR/SBR	Twaron	423,6	113,6	16,7%	41,7%
Rubber 2	NR/SBR with 1.5phr Sulfron 3001	Twaron	392,7	104,9	22,8%	46,1%
Rubber 3	NR/SBR with 2.0phr Sulfron 3001	Twaron	371,6	98,9	26,9%	49,2%
Rubber 4	NR/BR	Twaron	358,4	95,2	29,5%	51,1%
Rubber 5	NR/BR with 1.5phr Sulfron 3001	Twaron	313,7	82,6	38,3%	57,6%
Rubber 6	NR/BR with 2.0phr Sulfron 3001	Twaron	304,4	80,0	40,2%	58,9%

Table 6. Calculation results for overland conveyor KW-02.

Summary of calculation results for belt conveyor KW-03 @ 35 degrees C						
			Power requirement [kW]		Power savings [%]	
Rubber type		**Carcass type**	**Fully loaded**	**Empty**	**Fully loaded**	**Empty**
Rubber 1	NR/SBR	Steel cord	464,8	241,1	0,0%	0,0%
Rubber 2	NR/SBR with 1.5phr Sulfron 3001	Steel cord	423,1	222,3	9,0%	7,8%
Rubber 3	NR/SBR with 2.0phr Sulfron 3001	Steel cord	394,4	209,3	15,1%	13,2%
Rubber 4	NR/BR	Steel cord	376,6	201,3	19,0%	16,5%
Rubber 5	NR/BR with 1.5phr Sulfron 3001	Steel cord	316,2	174,0	32,0%	27,8%
Rubber 6	NR/BR with 2.0phr Sulfron 3001	Steel cord	303,6	168,3	34,7%	30,2%
Rubber 1	NR/SBR	Twaron	397,1	164,3	14,6%	31,9%
Rubber 2	NR/SBR with 1.5phr Sulfron 3001	Twaron	360,7	151,5	22,4%	37,2%
Rubber 3	NR/SBR with 2.0phr Sulfron 3001	Twaron	335,7	142,6	27,8%	40,8%
Rubber 4	NR/BR	Twaron	320,1	137,2	31,1%	43,1%
Rubber 5	NR/BR with 1.5phr Sulfron 3001	Twaron	267,4	118,6	42,5%	50,8%
Rubber 6	NR/BR with 2.0phr Sulfron 3001	Twaron	256,4	114,7	44,8%	52,4%

Table 7. Calculation results for overland conveyor KW-03.

Summary of calculation results for belt conveyor KW-05 @ 35 degrees C						
			Power requirement [kW]		Power savings [%]	
Rubber type		Carcass type	Fully loaded	Empty	Fully loaded	Empty
Rubber 1	NR/SBR	Steel cord	690,6	295,5	0,0%	0,0%
Rubber 2	NR/SBR with 1.5phr Sulfron 3001	Steel cord	634,6	272,4	8,1%	7,8%
Rubber 3	NR/SBR with 2.0phr Sulfron 3001	Steel cord	596,2	256,6	13,7%	13,2%
Rubber 4	NR/BR	Steel cord	572,3	246,7	17,1%	16,5%
Rubber 5	NR/BR with 1.5phr Sulfron 3001	Steel cord	491,2	213,3	28,9%	27,8%
Rubber 6	NR/BR with 2.0phr Sulfron 3001	Steel cord	474,3	206,3	31,3%	30,2%
Rubber 1	NR/SBR	Twaron	599,8	201,4	13,2%	31,9%
Rubber 2	NR/SBR with 1.5phr Sulfron 3001	Twaron	550,9	185,6	20,2%	37,2%
Rubber 3	NR/SBR with 2.0phr Sulfron 3001	Twaron	517,3	174,8	25,1%	40,8%
Rubber 4	NR/BR	Twaron	496,5	168,1	28,1%	43,1%
Rubber 5	NR/BR with 1.5phr Sulfron 3001	Twaron	425,7	145,3	38,4%	50,8%
Rubber 6	NR/BR with 2.0phr Sulfron 3001	Twaron	410,9	140,6	40,5%	52,4%

Table 8. Calculation results for overland conveyor KW-05.

From Tables 5 to 8 it can be learned that the addition of Sulfron seriously decreases the drive power requirement of the four belt conveyors. When added in 2 phr to a NR/SBR rubber it reduces the power consumption of a fully loaded belt up to about 13%. For an empty belt this reductions is also about 13%. If in addition, the SBR rubber is changed for BR rubber, then an additional 16% reduction is achieved both for a fully loaded belt as well as an empty belt. If the steel cord carcass is changed for a Twaron carcass then the power consumption decreases further. Again in the case where 2 phr is added to a NR/SBR rubber, it reduces the power consumption of a fully loaded belt up to about 26%. For an empty belt this reductions is also about 45%. If in addition, the SBR rubber is changed for BR rubber then an additional 15% reduction is achieved for a fully loaded belt and an additional 11% for an empty belt. This information is summarised in Table 9. Finally, Table 10 gives an overview of the maximum possible energy savings. As follows from this table, maximum energy savings are obtained in the cases where 2 phr Sulfron is added to a NR/BR rubber and a Twaron carcass is used. Looking at the possible energy savings varying between the 40% and 60%, it is fair to say that with these belts the next generation low loss conveyor belts have been found.

Summary of calculation results			Maximum power savings [%]	
Belt conveyor	Rubber type	Carcass type	Fully loaded	Empty
KW-01	NR/SBR with 2.0phr Sulfron 3001	Steel cord	11,8%	13,2%
	NR/BR with 2.0phr Sulfron 3001	Steel cord	26,9%	30,3%
	NR/SBR with 2.0phr Sulfron 3001	Twaron	25,2%	49,4%
	NR/BR with 2.0phr Sulfron 3001	Twaron	37,7%	59,3%
KW-02	NR/SBR with 2.0phr Sulfron 3001	Steel cord	12,4%	12,9%
	NR/BR with 2.0phr Sulfron 3001	Steel cord	28,4%	29,6%
	NR/SBR with 2.0phr Sulfron 3001	Twaron	26,9%	49,2%
	NR/BR with 2.0phr Sulfron 3001	Twaron	40,2%	58,9%
KW-03	NR/SBR with 2.0phr Sulfron 3001	Steel cord	15,1%	13,2%
	NR/BR with 2.0phr Sulfron 3001	Steel cord	34,7%	30,2%
	NR/SBR with 2.0phr Sulfron 3001	Twaron	27,8%	40,8%
	NR/BR with 2.0phr Sulfron 3001	Twaron	44,8%	52,4%
KW-05	NR/SBR with 2.0phr Sulfron 3001	Steel cord	13,7%	13,2%
	NR/BR with 2.0phr Sulfron 3001	Steel cord	31,3%	30,2%
	NR/SBR with 2.0phr Sulfron 3001	Twaron	25,1%	40,8%
	NR/BR with 2.0phr Sulfron 3001	Twaron	40,5%	52,4%

Table 9. Summary of calculation results for all overland conveyors.

Summary of calculation results			Maximum power savings [%]	
Belt conveyor	Rubber type	Carcass type	Fully loaded	Empty
KW-01	NR/BR with 2.0phr Sulfron 3001	Twaron	37,7%	59,3%
KW-02	NR/BR with 2.0phr Sulfron 3001	Twaron	40,2%	58,9%
KW-03	NR/BR with 2.0phr Sulfron 3001	Twaron	44,8%	52,4%
KW-05	NR/BR with 2.0phr Sulfron 3001	Twaron	40,5%	52,4%

Table 10. Maximum energy savings for all overland conveyors.

It should be noted that changing a steel cord carcass for an aramid carcass reduces the static splice strength from 100% to about 75% and the dynamic splice strength from 60% to about 50%. If the rating of the belt is not changed then that is no problem. However, a substantial reduction in power consumption will lead to a serious reduction of the maximum belt tensions. This may justify a reduction in the rating of the belt used. This effect has not been investigated.

The other effect that has not been analysed in depth is the effect of changing from a discontinuous carcass with cables to a continuous carcass with straight warp or solid woven aramid fabric. The indentation rolling resistance depends on the thickness of the bottom cover as illustrated in equation 1. In the case of a steel cord carcass the effective bottom cover thickness is the real thickness of the bottom cover plus about half the cable diameter of the applied steel cords [8]. In the case of an aramid carcass it is only the actual thickness of the bottom cover. Therefore, on this basis alone it is to be expected that a change from a steel cord carcass to an aramid carcass reduces the indentation rolling resistance. This effect, however, has not been incorporated in the calculations summarised above.

4.3 Feasibility Study

From Section 4.2 it follows that substantial power savings are possible when aramid products are applied in conveyor belting and when a BR rubber is used instead of an SBR rubber. However, it is not only benefits that are achieved with this combination. The aramid products come with a cost both in terms of the product as well as an increase in production cost if the production process of the compound or the formation of the belt needs to be altered. The costs of Sulfron and the implication on the production process are known accurately. The cost of a production change when using Twaron and a change to BR rubber are not precisely .known. Therefore, in order to analyse the feasibility of the application of aramid products, only the addition of Sulfron in 2 phr is studied.

Sulfron costs about 20 €uro per kilo. Knowing the amount of Sulfron added to the rubber compound of the bottom cover, 1,5 phr or 2 phr, the extra costs per belt width can be calculated for a bottom cover with a thickness of 4 mm as used in the Optimum conveyor belts (Table 11).

	Addition of Sulfron 3001	
Belt width	1,5 phr	2,0 phr
1200 mm	€ 1,66	€ 2,21
1050 mm	€ 1,45	€ 1,93

Table 11. Additional costs of adding Sulfron in the 4 mm thick bottom cover per metre belt.

Knowing that the addition of 2 phr Sulfron gives the biggest energy savings, the costs of using a NR/SBR bottom cover with 2 phr Sulfron have been calculated (Table 12). The vulcanization properties of the rubbers 2 to 6 are similar to rubber 1. This means that a low loss bottom cover can be applied together with a more conventional top cover which makes the combination as mentioned feasible.

Belt conveyor	Tape length [m]	Costs
KW-01	10.580	€ 23.361
KW-02	5.408	€ 11.941
KW-03	7.448	€ 14.390
KW-05	6.624	€ 12.798

Table 12. Costs of adding Sulfron in the bottom cover per belt conveyor.

Knowing the exact energy savings from the calculation results presented in Section 4.2, the cost savings can be calculated. The cost savings consist of both the reduced costs for energy as well as the reduced CO_2 compensation fees as discussed in [9]. For this calculation it is assumed that the belt conveyors run under full load for 75% of the time and that they run empty for 5% of the time. The other 20% of the time it is assumed that the conveyors are not running. If the interest and depreciation effects are neglected then the payback time of the investment in a next generation low loss bottom cover can be calculated by dividing the costs per belt (last column of Table 12) by the cost savings (6th column of Table 13). The results are presented in the last column of Table 13. From that column it can be seen that the payback time is two to three months. That justifies the negligence of the interest and depreciation effects. A payback period of two to three months is excellent considering the economic life of a belt.

	Difference in power (rubber 1 vs 3)		Energy saving	CO2 savings	Cost savings	Pay back time
Belt conveyor	Fully loaded [kW]	Empty [kW]	[kWh]	[Ton]	[Euro]	[Months]
KW-01	176	66,8	98.798	53	€ 10.680	2,2
KW-02	63,1	25,2	35.467	19	€ 3.834	3,1
KW-03	70,36	31,8	39.683	21	€ 4.290	3,4
KW-05	94,4	38,9	53.104	29	€ 5.741	2,2

Table 13. Costs savings and payback time per belt conveyor.

It is therefore fair to say that the investment in a next generation low loss rubber for the bottom cover is more than justified. It is expected that also an investment in the next generation conveyor belting using NR/BR rubber and a Twaron carcass will be justified considering the additional energy savings that they will bring.

5. CONCLUSION

Based on the analyses discussed in the Section 4.2 it can be concluded that the application of aramid materials in a conveyor belt, like Sulfron and Twaron, in conjunction with the application of a NR/BR, rubber drastically reduces the energy consumption of a belt conveyor. Should these belts be used in the four belt conveyors of the Optimum overland system, then the overall maximum energy savings would be between 40% and 60%. On that basis it is fair to say that with these belts the next generation low loss conveyor belts can become a reality.

The feasibility of the utilisation of Sulfron in a conveyor belt was analysed in Section 4.3. From that analysis it can be concluded that the payback time is two to three months, which is excellent. Besides the financial benefit, the environmental benefits in terms of a substantial reduction in the emission of, for example, $CO_{2,}$ should also be a major driver in deciding to change to the next generation low loss conveyor belts.

Finally, although the analyses set forth in this paper have been carried out with utmost care and are based on commonly accepted theories, it should be noted that it is still theory even though the rubber properties are determined experimentally. Therefore the next phase in the research into the next generation conveyor belts is to apply Sulfron and Twaron in a real conveyor belt using NR/SBR rubber and NR/BR and test it under laboratory and practical conditions.

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