Replacing C-6 Conveyor Belt at Kennecott Copper, Bingham Canyon Copper Mine

Dr. Robin B. Steven
The Goodyear Tire & Rubber Company

SYNOPSIS

With the economic pressures of a constantly fluctuating commodity market the success of a large mining operation depends on its ability to constantly improve its efficiency and meet its goals on a daily basis. Careful planning and original equipment selection form the foundation of the mine. However, careful daily planning and execution is necessary to make the mine a success. Equipment reliability is a key component to that success and can ultimately be measured in terms of the equipment's cost per ton of material mined. For many copper mines conveyor belts are the principal lifeline for the mined material between the ore body and the processing plant. In many cases these lifeline belt conveyors are many kilometers long. The true value of these conveyor belt lines is measured in terms of their return in performance when compared to their initial capital and operating costs. Reliability is the key. This paper discusses the performance of a 11,558 m (38,000 ft) 1829 mm (72") wide ST3500 belt which was changed out in August 2002 after almost 14 years of service and of the developments incorporated in the replacement belt. Laboratory test results of the original and replacement belt's physical properties are given and compared and the performance of the belt's rip detection system is discussed as well as enhancements in this area. Belt changeout had to occur in a short predetermined time. In order to accomplish this the belt was spliced ahead of time and reefed out ready to be pulled on quickly, details are included. New splicing methods and a detailed splice specification were adopted to ensure a 60% dynamic splice efficiency for the replacement belt. Dynamic splice testing was conducted on Goodyear's two-pulley test machine with a ST10,000 capability in Marysville, Ohio details of which are also described..

INTRODUCTION

Fig 1. 1999 Aerial View of Bingham Canyon Mine Pit

Rio Tinto's Kennecott Utah Copper Bingham Canyon Mine is the largest open pit copper mine in the world, located about 45 kilometers (28 miles) southwest of Salt Lake City, Utah. Mineral deposits were discovered there in 1863 and mining has continued in one form or another to the present day. At 4 kilometers (2.5 miles) wide and 1.2 kilometers (0.75 miles) deep it is considered the largest excavation on the planet and can be seen from outer space.

A review of its history reveals a series of investments in new technologies which together with a strict discipline of good maintenance has kept the mine leading the world in terms of its productivity .

Before the turn of the century, the mine was developed for it's silver and gold deposits which were extracted using underground mining methods of the day. Copper was not mined until after 1898 when surface mining methods involving the mass production of low-grade copper ore were shown to be profitable [1]. In 1906 the Utah Copper Company and the Boston Consolidated Mining Company made the first cuts into the mountain to remove the copper ore using steam driven shovels The ore was transported from the mine by rail-car. The Utah

Copper Company purchased the Boston Consolidated Mining Company in 1912 and were themselves purchased in1936 by the Kennecott Copper Corporation, at that time the workforce was around 5,000 workers.

Fig.2 Early Steam Shovel and Rail-car

In the 1950's Kennecott constructed a refinery and purchased a nearby smelter giving them a completely integrated copper production process from mining through concentrating, smelting and refining.
In the 1960's they implemented a $100 million expansion and modernization adding haulage trucks, large drills. and electric shovels.

Fig.3 Electric Shovel and Trucks

In the 1970's they executed a further $300 million modernization of their smelter complex.

In the1980's the mine went through yet another modernization, this time a $400 million project that included the construction of an in-pit crusher, a conveying system and a new concentrator. This project was completed in 1988 and helped make Kennecott Utah Copper the lowest cost copper producer in the world at that time.

The conveyors in this expansion transported 254mm (10") minus crushed ore from the in-pit crusher to the concentrator. The longest conveyor of this expansion was designated C-6. It was 5.288 km (17,352 ft) long and ran in a tunnel from the pit wall through the mountain-side to other conveyors that took the crushed ore to the concentrator. The C-6 conveyor belt was commissioned in January 1988 and ran until it was removed in August 2002 after carrying 700 million tons. The success of this belt has prompted the writing of this paper which discusses both its performance and the selection of the belt that replaced it.

Today, using current technologies, mining is still executed by a sequence of drilling, blasting, loading, hauling crushing, conveying, concentrating, smelting and refining and is carried out 24 hours a day, 365 days a year with 12 hours maintenance every 2 weeks. Additional time is allowed for crusher lining maintenance. The mine removes on average around 450,000 tons of material (ore and waste) a day and produces copper, gold, silver, molybdenum and sulfuric acid. The Kennecott currently employs around 1700 workers with around 800 at the minesite.

Fig.4 Today's Trucks and Shovel

C-6 CONVEYOR

With the in-pit crusher development Kennecott implemented a conveyor system incorporating six conveyors to transport the crushed ore from the in-pit crusher to a stockpile outside the pit. From a short feeder belt (M-3) beneath the crusher the ore was transferred to M-4 (134m), C-6 (5,288m), C-7 (549m), C-8 (2,130m) and then to C-9 (122m) from which it discharged onto the stockpile, Figure 5.

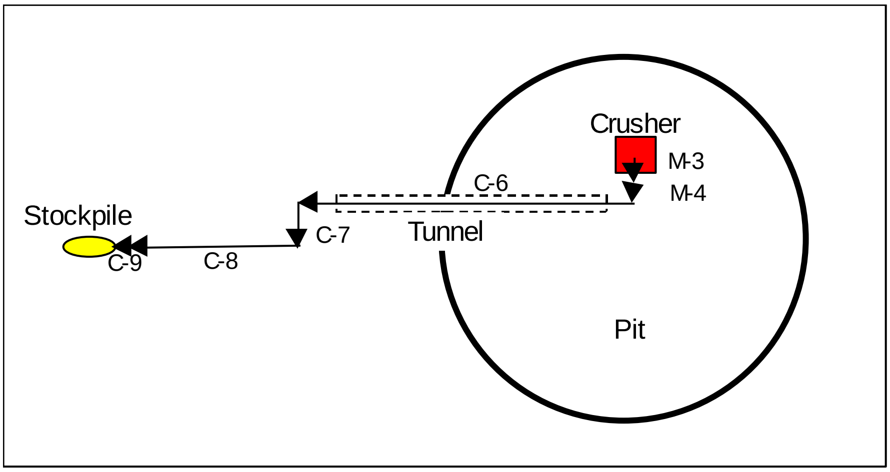


Fig. 5 Schematic drawing of 1988 in-pit crusher conveyor system

All conveyors from M4 to C8 were a common belt specification, 1829mm (72") ST3500 with 16mm (5/8") x 6mm (1/4") covers, and ran on rigid, 178mm (7") diameter, 35 degree troughing idlers with 15 degree V-returns. These belts operated at 4.52 m/s (890 fpm) with a peak design capacity of 9,070 mtph. M-3 was a 2997mm (118") ST1750 with 7/8" x 3/8" covers and C-9 was a 2438mm (96") ST1250 with 3/4" x 1/4" covers.

C-6 was 5,288m (17,352 ft) center to center length with a 4m (13 ft) drop. It was driven by a 1,120 kW (1500 HP) primary and secondary drive at the head with one additional 1,120 kW (1500 HP) drive at the tail. The great majority of the conveyor length was inside a tunnel where the rail line had previously been, see Figure 6. A conventional rock box loading chute was used.

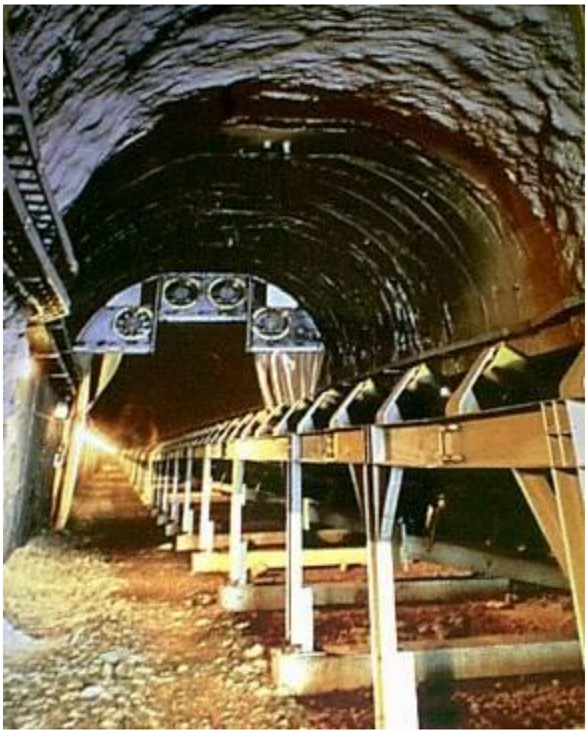


Fig. 6 C-6 Conveyor in the tunnel

C-6 BELT CONSTRUCTION

The belt selected for C-6 was a 72" wide ST3500 with 5/8" x 1/4" RMA Grade I natural rubber covers. The belt had 106 x 8.3mm diameter 19+6x12 galvanized steel cords. Cord selection was based on a 6.67:1 safety factor, good dynamic performance and an open cord design to ensure good rubber penetration . Figure 7 illustrates the basic belt construction.

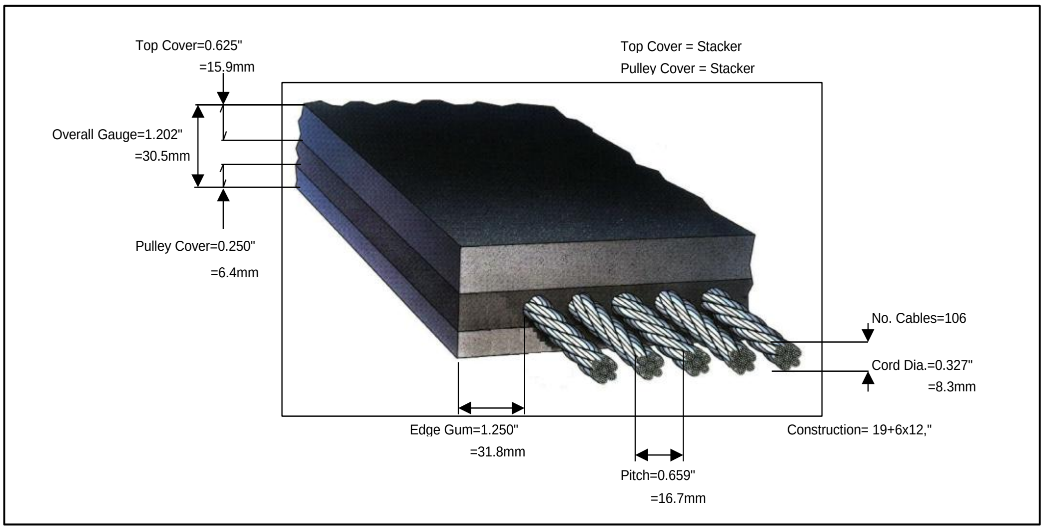


Fig.7 C-6's 72" ST3500 belt construction

The cover compound and gauges were selected to meet the heavy duty cut and gouge service and to satisfy the cover wear warranty of 10 years or 285 million tons.

BELT WEAR

Fig. 8 Measuring belt cover gauge

Cover gauge measurements on the top cover were made periodically on the belts using special gauging equipment, Fig.8. The equipment determines the belt gauge from a probe that is placed on the belt surface. The technique is based on the principal that there is a known relationship between the strength of an electromagnetic field induced by the probe in the steel cords and the gauge of the rubber between the probe surface and the cords. After being calibrated for the belt to be measured the correct belt cover gauge is displayed directly on the hand held meter attached to the probe. Typically, measurements were taken every 152mm (6") across the belt width. In this way a gauge profile could be generated for each belt. Ideally, the same position on the belt should be used for subsequent gauge measurements. However, previous studies have indicated that there is little variation in gauge profile along the belt.

Figure 9 illustrates the top cover wear measurements recorded for C-6.

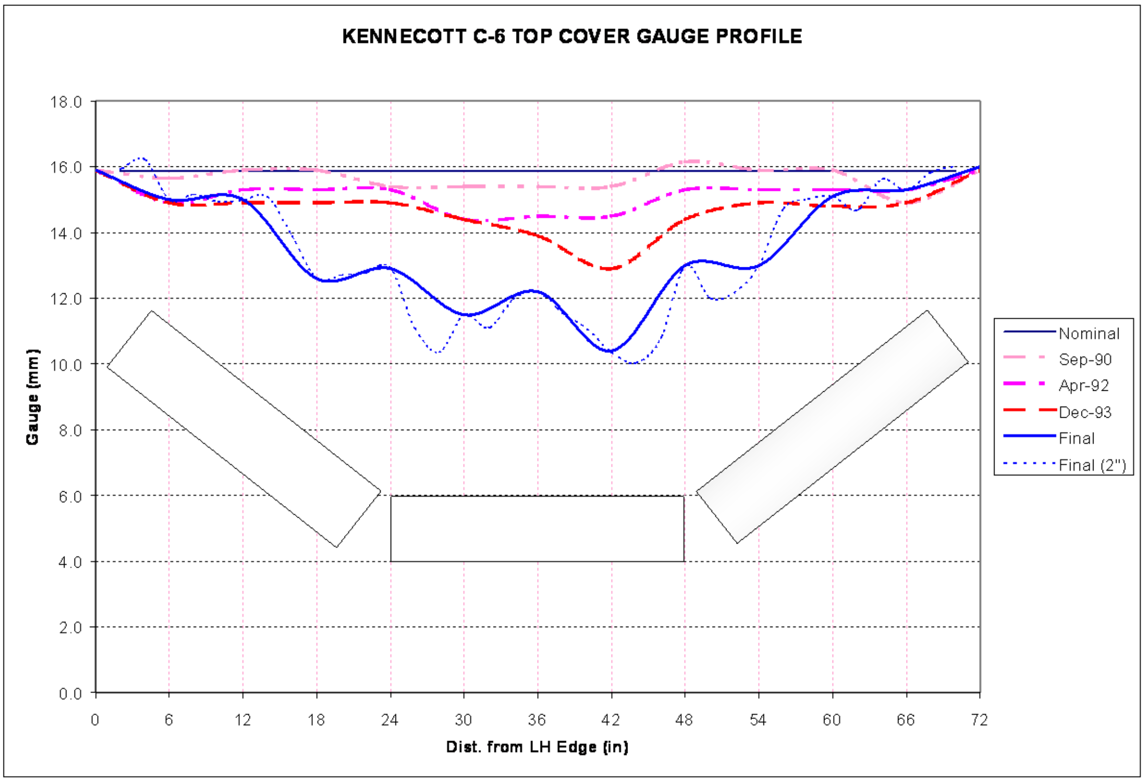


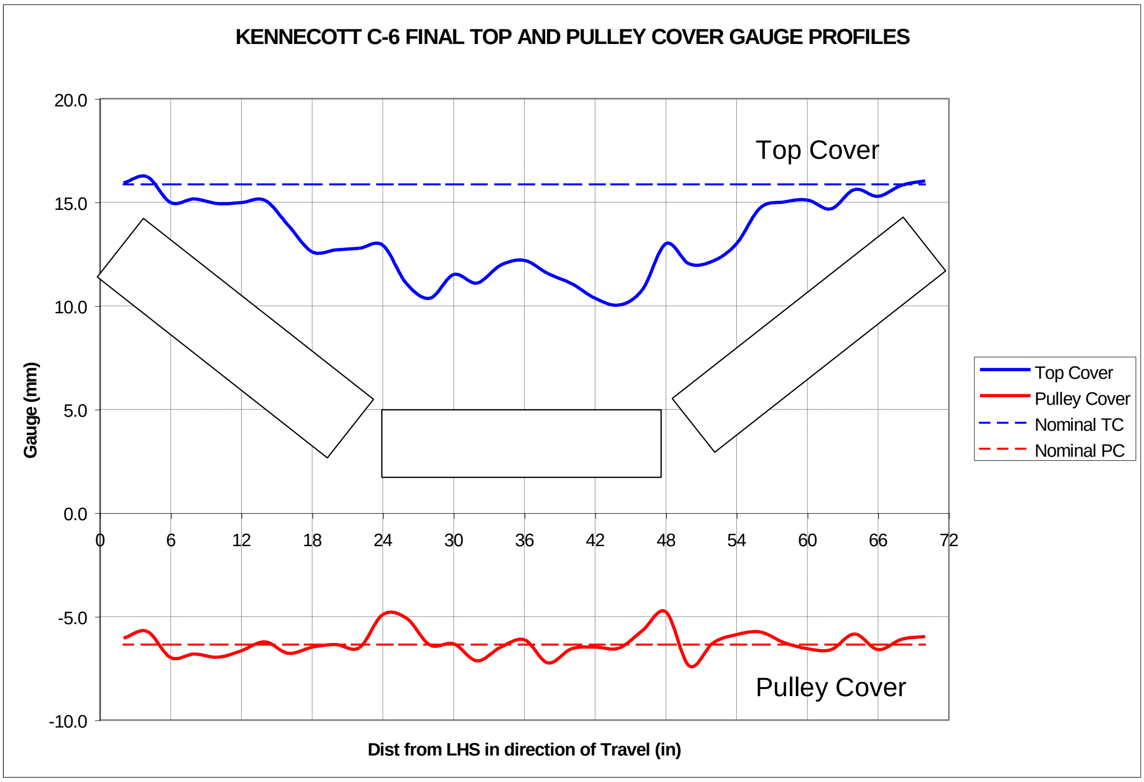
Fig. 9 Top cover gauge profiles for C-6

A sample of the belt was returned for analysis after the belt's replacement in August 2002. Final cover gauge measurements were made in the manufacturer's laboratory. These measurements were made at 51mm (2") increments instead of 152mm (6") and were made using an Ames gauge on the cut end of the belt. Figure 9 shows the final top cover gauge data as the lower (blue) lines. The dotted lower (blue) line shows the data plotted at the measured 51mm (2") increments and the solid lower (blue) line shows the same data plotted at 152mm (6") increments, that is, at the same frequency as the field measurements were taken. Comparing the dotted and solid blue lines reveals that significant data may be missing from data taken at 152mm (6") increments, lowest gauge points may be missed.

The final top cover wear pattern shows irregularities in the region of the idler roll junctions. Peak wear points occurred approximately 100mm (4") in-board of the center idler roll ends. It is apparent that this is related to the material loading pattern, lump size and the configuration of the belt in the idler junction zones. The center wear pattern can be seen on the belt surface of the returned sample, see Figure 10. However, in general the belt shows very little top cover wear considering its age and the volume of material it has conveyed.

Fig. 10 Belt sample returned to Conveyor Belt Technical Center

No field measurements were taken of the pulley cover gauge profile but Figure 11 shows the laboratory measurements on the returned sample for both top and pulley covers with the pulley cover inverted so as to appear as it would if one were looking at one end of the belt. The pulley cover gauge results show very little wear but reveal profile irregularities again corresponding to the idler junction gap area.



.Fig. 11 C-6 Final top and pulley cover gauge profiles

Belt cover wear life was warranted to last 10 years or 285 million tons. Tonnage figures were kept at the mine and Figure 12 shows how this belt performed against its warranted life. After almost 14 years of service and transporting almost 700 million tons the belt surpassed both time and tonnage expectations.

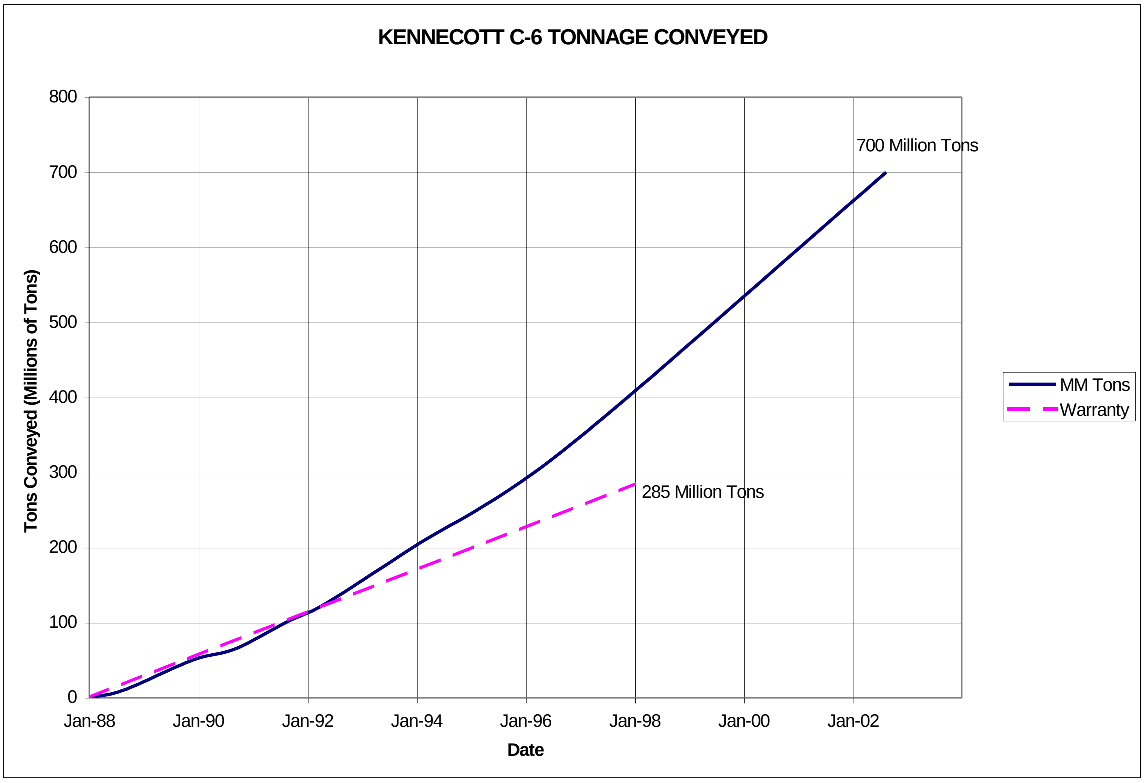


Fig. 12 C-6 Tons conveyed versus warranty

BELT CONDITION AFTER SERVICE

The belt sample returned for analysis was subjected to standard laboratory physical tests to establish its condition after almost 14 years of service. These included top and pulley cover hardness, abrasion, rubber tensile strength and elongation both as received and after heat aging, tear tests, insulation to cover rubber adhesion, and cord pullout tests Figures 13, 14. 15 and Table 1 illustrates the results.

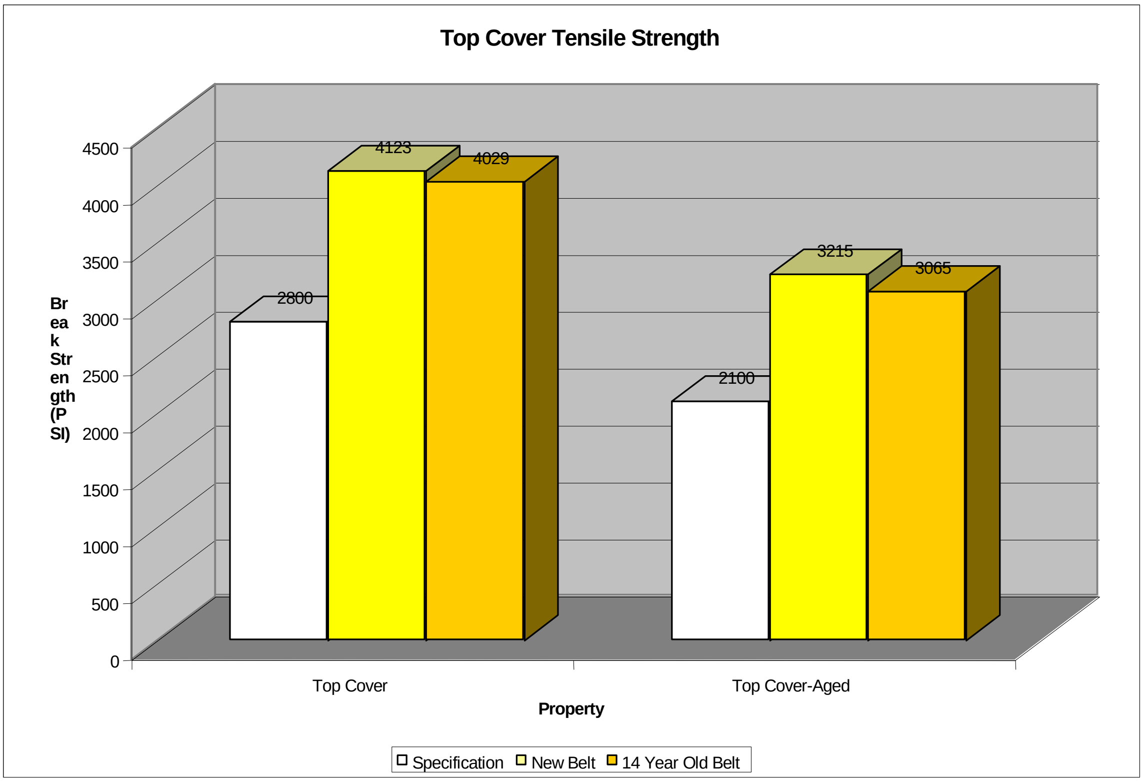


Fig.13-(a) Top Cover tensile strength compared to specification and original values

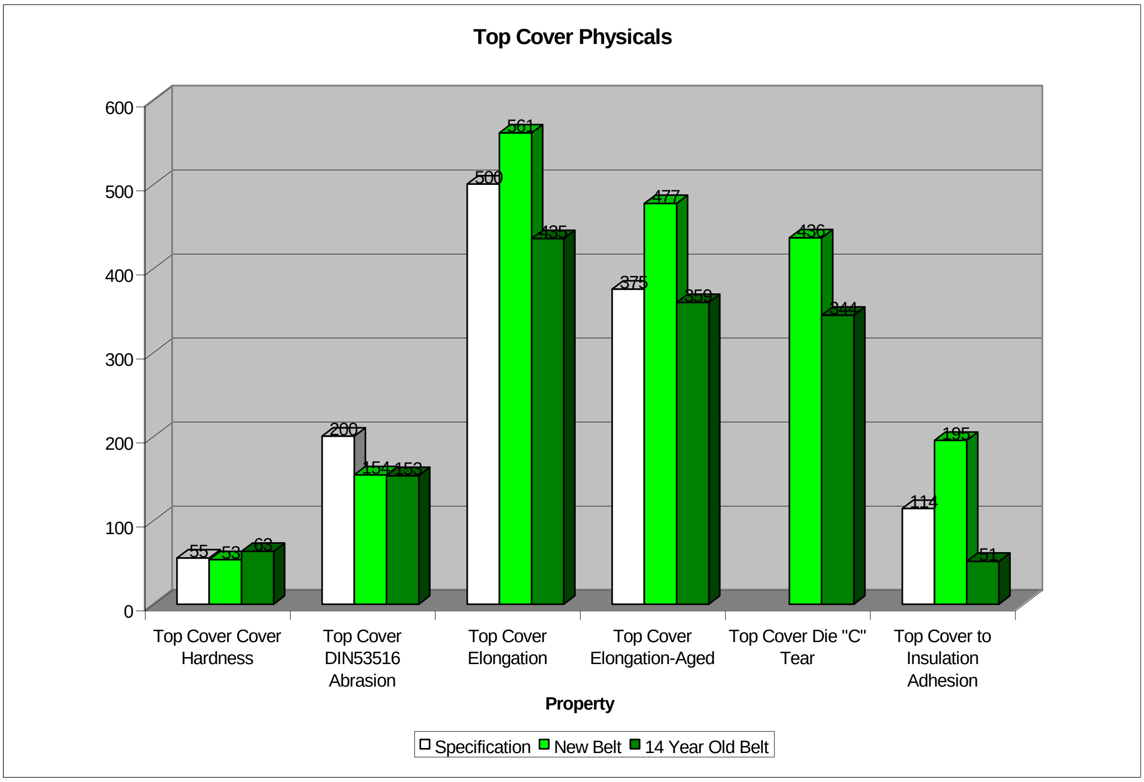


Fig. 13-(b)) Top Cover physical properties compared to specification and original values

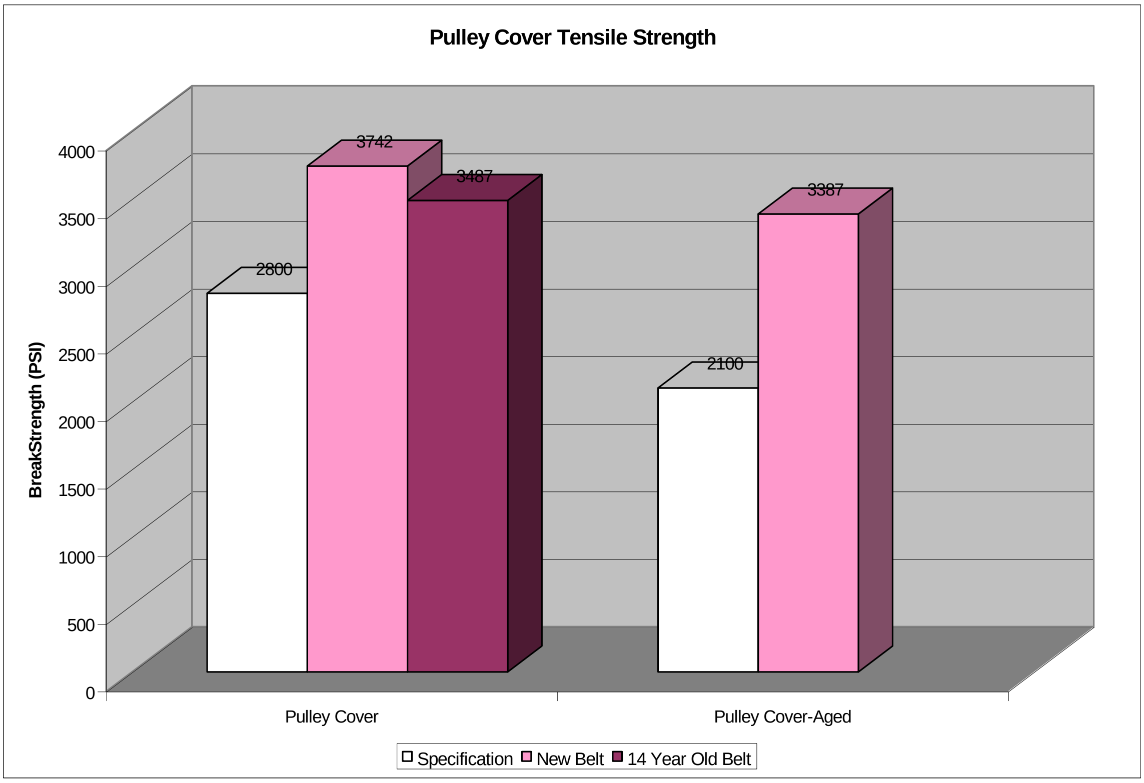


Fig. 14-(a) Pulley Cover tensile strength compared to specification and original values

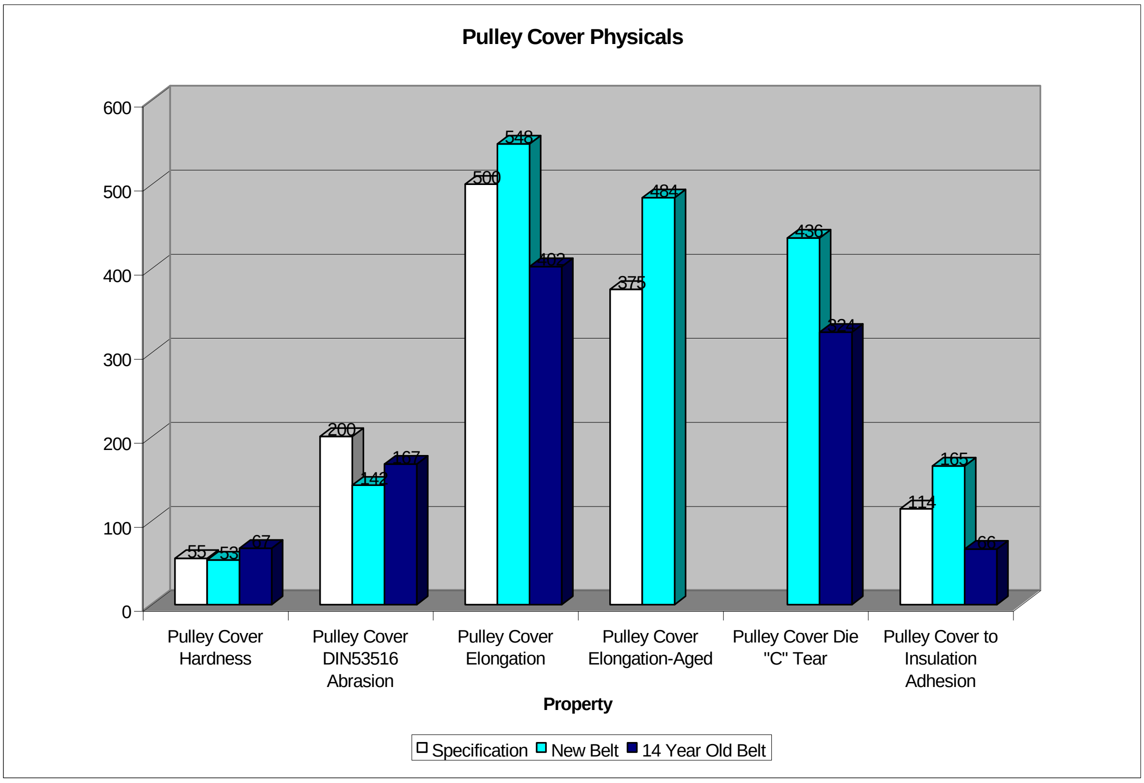


Fig. 14-(b) Pulley Cover physical properties compared to specification and original values

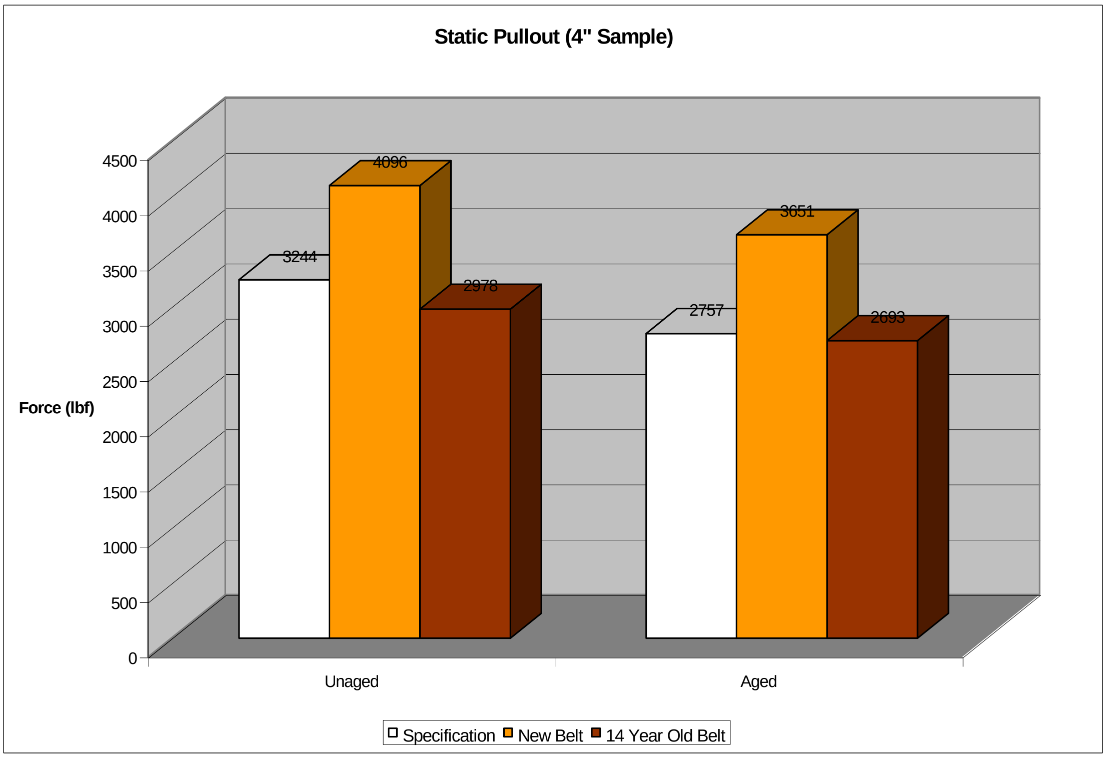


Fig. 15 C-6 Pullout adhesions compared to specification and original values

Test Parameter	Units	Specification	New Belt	14 Year Old Belt	Change
Static Cord Pullout (4" Sample)	lb	3244	4096	2978	-27.3%
Static Cord Pullout (4" Sample)-Aged	lb	2757	3651	2693	-26.2%
Test Parameter	Units	Specification	New Belt	14 Year Old Belt	Change
Top Cover Cover Hardness	Shore A	55	53	63	18.9%
Top Cover DIN53516 Abrasion	cu.mm.	200	154	153	-0.6%
Top Cover Tensile Strength	PSI	2800	4123	4029	-2.3%
Top Cover Tensile Strength-Aged	PSI	2100	3215	3065	-4.7%
Top Cover Elongation	%	500	561	435	-22.5%
Top Cover Elongation-Aged	%	375	477	359	-24.7%
Top Cover Die "C" Tear	lb		436	344	-21.1%
Top Cover to Insulation Adhesion	piw	114	195	51	-73.8%
Test Parameter	Units	Specification	New Belt	14 Year Old Belt	Change
Pulley Cover Hardness	Shore A	55	53	67	26.4%
Pulley Cover DIN53516 Abrasion	cu.mm.	200	142	167	17.6%
Pulley Cover Tensile Strength	PSI	2800	3742	3487	-6.8%
Pulley Cover Tensile Strength-Aged	PSI	2100	3387		
Pulley Cover Elongation	%	500	548	402	-26.6%
Pulley Cover Elongation-Aged	%	375	484		
Pulley Cover Die "C" Tear	lb		436	324	-25.7%
Pulley Cover to Insulation Adhesion	piw	114	165	66	-60.0%

Table 1 Data summary of returned belt versus new belt and specification

From the data it can be seen that with the exception of cover to insulation adhesion the old belt physicals are close to the original factory physicals. It can also be noted that the original factory physicals easily exceeded the original specifications.

From the wear and physical properties data it appears as though the belt is still in a good serviceable condition, so why was it replaced? The answer is two-fold. Kennecott was aware that cord damage was increasing and also that they were going to have a ten day shutdown when the crusher was relocated. Primarily it was to take advantage of the planned downtime during relocation of the crusher which was planned and executed by the Denver, Colorado office of Takraf.

With regard to the cord breaks, Fig. 16 shows how local impact damage initiates corrosion which leads to cord breaks and Fig. 17 shows the incidence of cord breaks plotted against time.

Fig. 16 Example of cord corrosion initiated from impact damage

Cord breaks were determined from non-destructive electromagnetic scanning of the belt which was performed by Halkin International/Longview Inspection, Aurora, Colorado and, later, by Conveyor Belt Technology Corp., of Surrey, British Columbia, Canada..

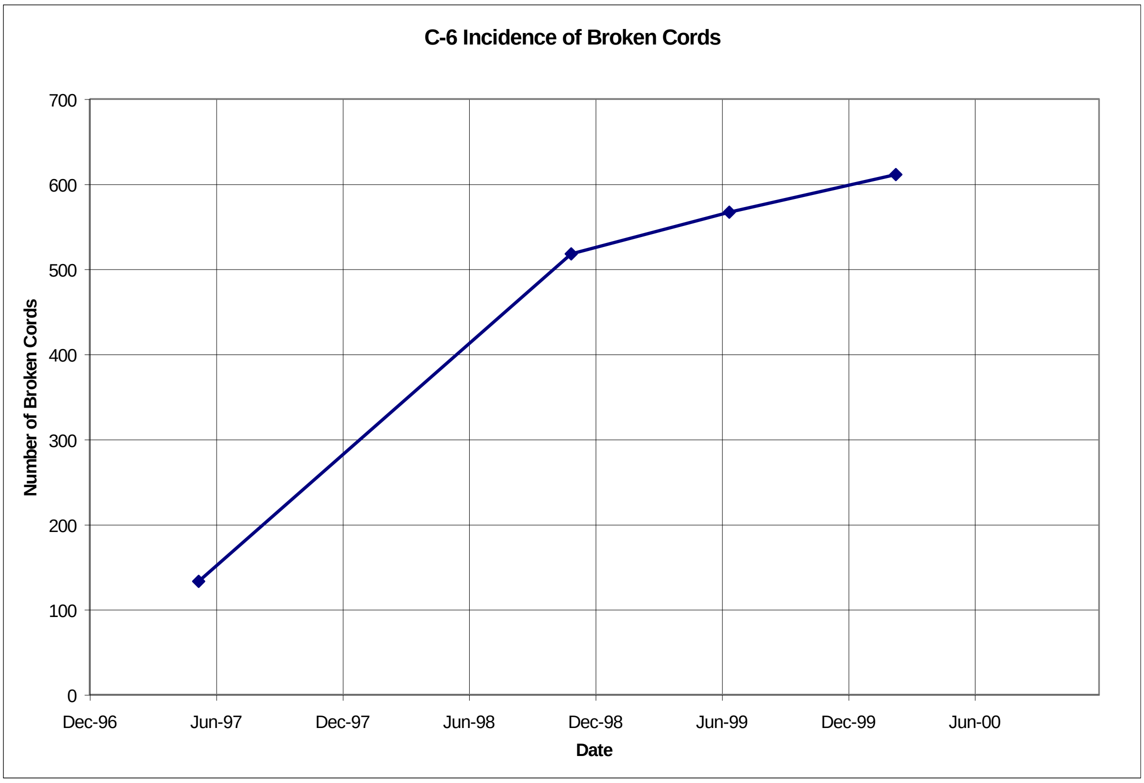


Fig. 17 Incidence of accidental cord damage in C-6 relative to time

After reviewing the data it was the manufacturer's view that if the number of cord breaks were to start increasing exponentially it would indicate cord fatigue and signal a sense of urgency to replace the belt. A moderate increase in the cord breaks would depict normal wear and allow more time for a planned replacement.

In the case of C-6 it was considered that the cord breaks were not fatigue related. Kennecott subsequently chose to make the changeout coincide with already planned downtime associated with a crusher move when the conveyor system would be down for ten days.

RIP PROTECTION

The original C-6 belt was protected from accidental rip damage by a proprietary rip detection system, with stainless steel wire sensor loops embedded at regular intervals in the belt beneath the cords. The system detects the loop integrity immediately after the load point and after the discharge point and stops the belt if a broken loop is detected. A loop would typically be broken if a piece of tramp metal penetrated the belt and then lodged against the chute or structure. The system worked well for the life of the belt and saved the belt on a number of occasions.

Later in the belt's life a number of sensor loops became damaged and no longer functioned correctly. After removing and analyzing these loops it was apparent that the majority of these bad loops were shorting at the wire cross-over in the center of the loop due to repetitive impact pounding. The wire cross-overs were part of the patented loop design that inverted the detected signal and enabled the detectors to differentiate between the rip sensing loops and tramp iron on the belt.

In order to minimize the problem the loop was redesigned in a way that eliminated the wire cross-over in the belt center and moved it out to the sides where there was little or no impact damage. The original and redesigned loop patterns are shown in Figures 18 and 19. The new style loops were used to replace non-functioning loops.

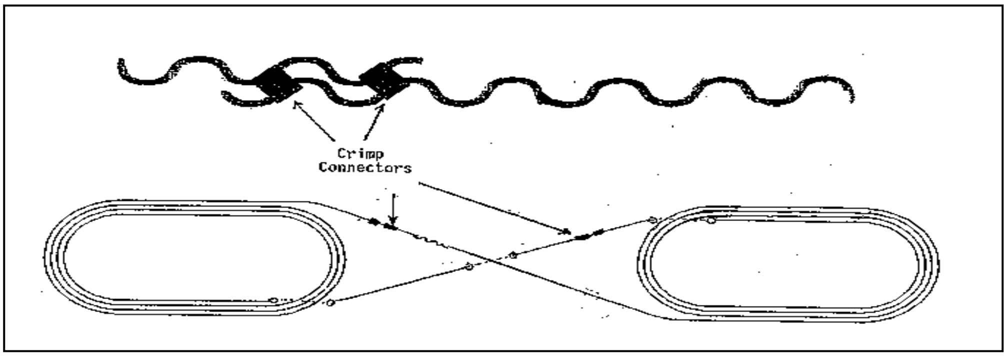


Fig. 18 Original Rip Sensor Loop Design

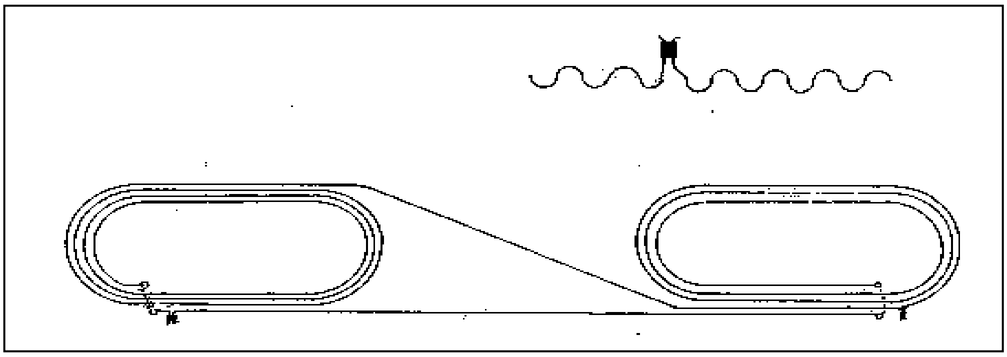


Fig. 19 Improved Rip Sensor Loop Design

BELT FLEET

Lateral movement of the belt or “fleet” measurements were taken for the original belt just prior to replacing the belt. Measurements were taken using an ultra-sonic distance measuring gauge mounted to one side of the belt and targeting the belt edge as indicated in Fig. 20. Belt fleet is the variation in the distance “D”. Data was recorded on a data logging unit and later downloaded for analysis. The data is shown in Fig.21.

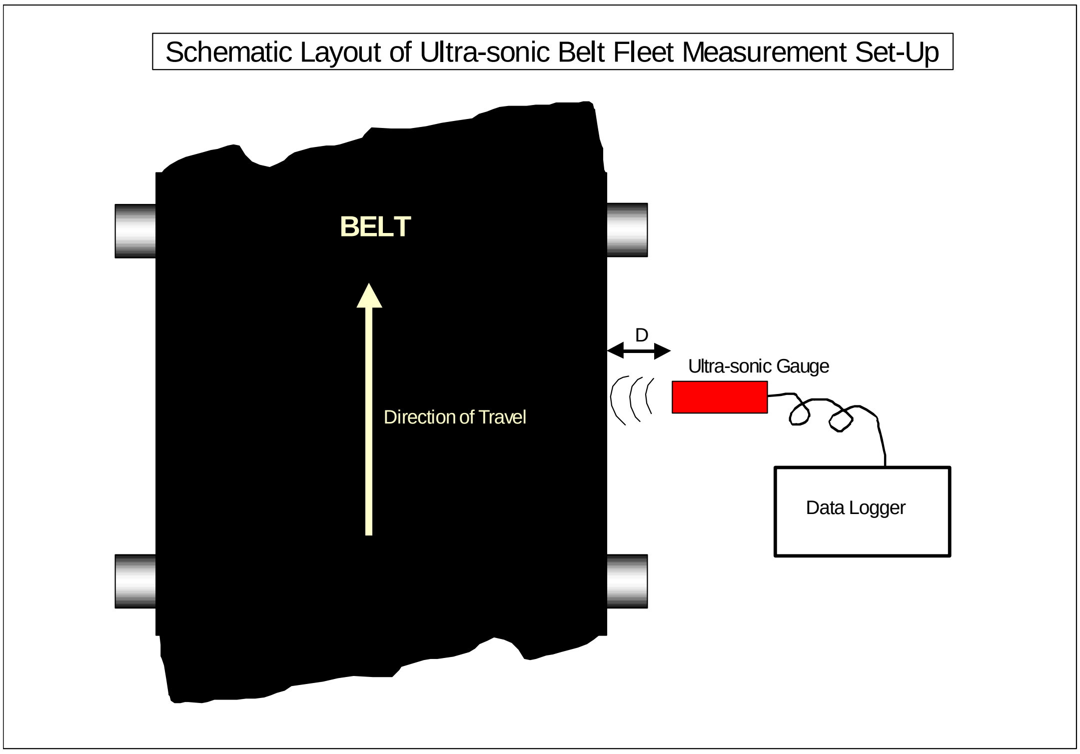


Fig. 20 Schematic layout of the ultra-sonic distance measuring equipment used to measure belt fleet.

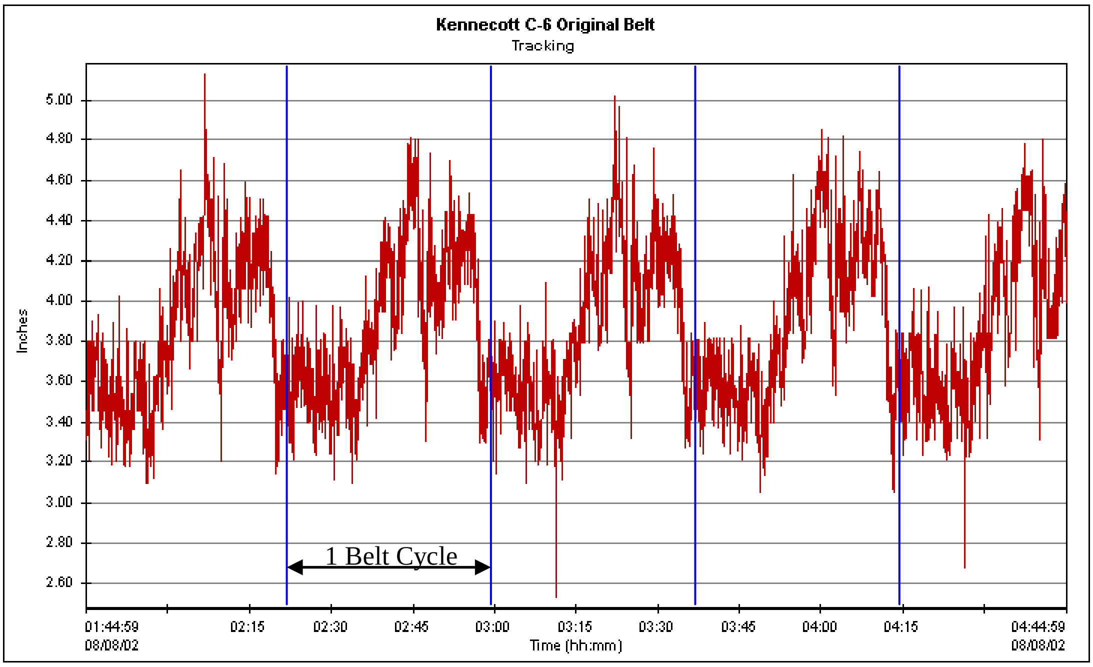


Fig.21 Ultra-sonic distance data recorded for position of edge of C-6 original belt

The fleet data was recorded every 2 seconds on the return side of the conveyor at a location 250 ft from the head. Fig. 21 shows the ultra-sonic edge position data for almost five complete revolutions of the belt The data shows a consistent “signature” for each revolution. The two second interval corresponds to about 30 ft of belt, which is one press length in the production process.

The recorded belt edge position varies between 3.10” (79 mm) and 4.85” (123 mm) with some excursions noted on some cycles. These excursions are due to the reading coinciding with a splice edge instead of the belt edge. From this study it was concluded that the belt’s total fleet variation was +/-0.875” (+/- 22 mm) for the original belt. This compares favorably with international standards DIN 22131, no more than +/- 75mm, or AS1333, no more than +/- 80mm.

REPLACEMENT BELT

After reviewing lighter weight and energy saving belt options, Kennecott elected to replace the belt with the same belt strength and covers specification as before.

The replacement belt was manufactured on the same production line as the original belt but benefited from an improved cord tensioning system. The original tensioning system provided a single preset hydraulic pressure which was common to all cord tensioning cylinders. Differences in seal friction and sheave wear caused variations in the final applied cord tensions. The improved system provided tension control with each individual cord having its own PLC controlled feedback loop This ensured very uniform cord tensions across the belt width. Fig. 22 illustrates typical cord tension distribution during production of the replacement belt using the new system.

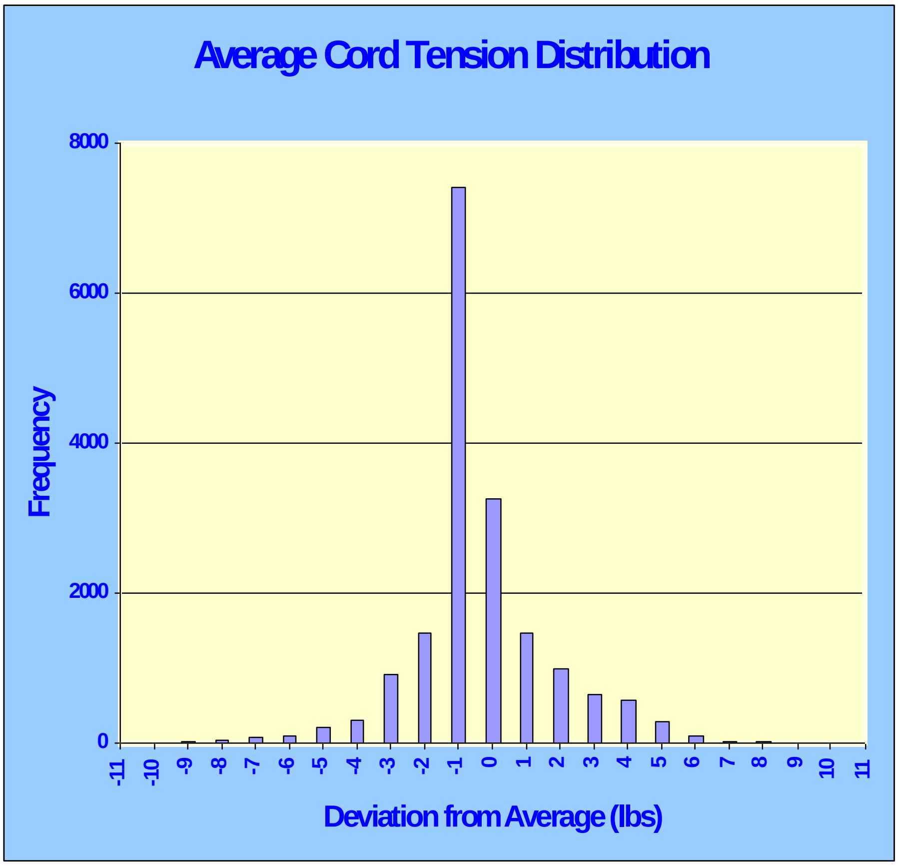


Fig. 22 Typical cord tension distribution of replacement belt

Uniform cord tensions across the belt width promotes good belt tracking. Belt tracking measurements taken of the replacement belt indicate a maximum edge position variation or fleet of +/- 0.76” (19 mm).

Belt physicals were as indicated for the “new” belt in Table 1, however, one new requirement was that the belt’s splice had to meet a 60% dynamic efficiency requirement.

SPLICES AND SPLICE TESTING

The original splices (24) on Kennecott’s C-6 were a 3200mm (126”) long two stage splice built on a 22 degree bias and had a 1041mm (41”) step length. No problems were experienced with the splices in the original belt and subsequent scans showed no loss of their structural integrity during the life of the belt. The scans also revealed that all splices had been made correctly and looked the same.

The original splice design was never dynamically tested. However, from test experience it was determined that the original splice would probably meet the new dynamic splice requirement of 60% dynamic splice efficiency with few changes. The manufacturer was able to test the dynamic splice efficiency on their 2-pulley Dynamic Splice Test Machine in the belt manufacturer’s Technical Center in Marysville Ohio. Fig 23

Fig.23 2-Pully Dynamic Splice Test Machine, in the manufacturer’s Technical Center

A 22 working cord test loop having ten repeat patterns was chosen for the test as being representative of the full splice. Fig. 24 shows the center section of the test splice cord pattern.

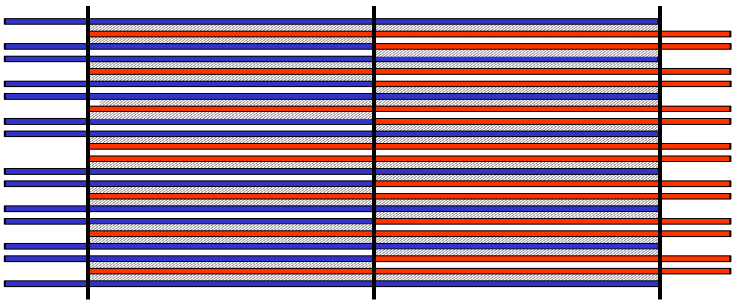


Fig. 24 Center section of splice test loop cord pattern

FEA analysis [2] was used to verify that the rubber shear stress and cord loads at 60% of breaking strength test load were within acceptable limits established for a dynamic splice test achieving 10,000 load cycles, Figs 25 and 26. Maximum shear stress was 2.48 MPa, maximum cord load was 33 kN. Two test loops were then built and tested..

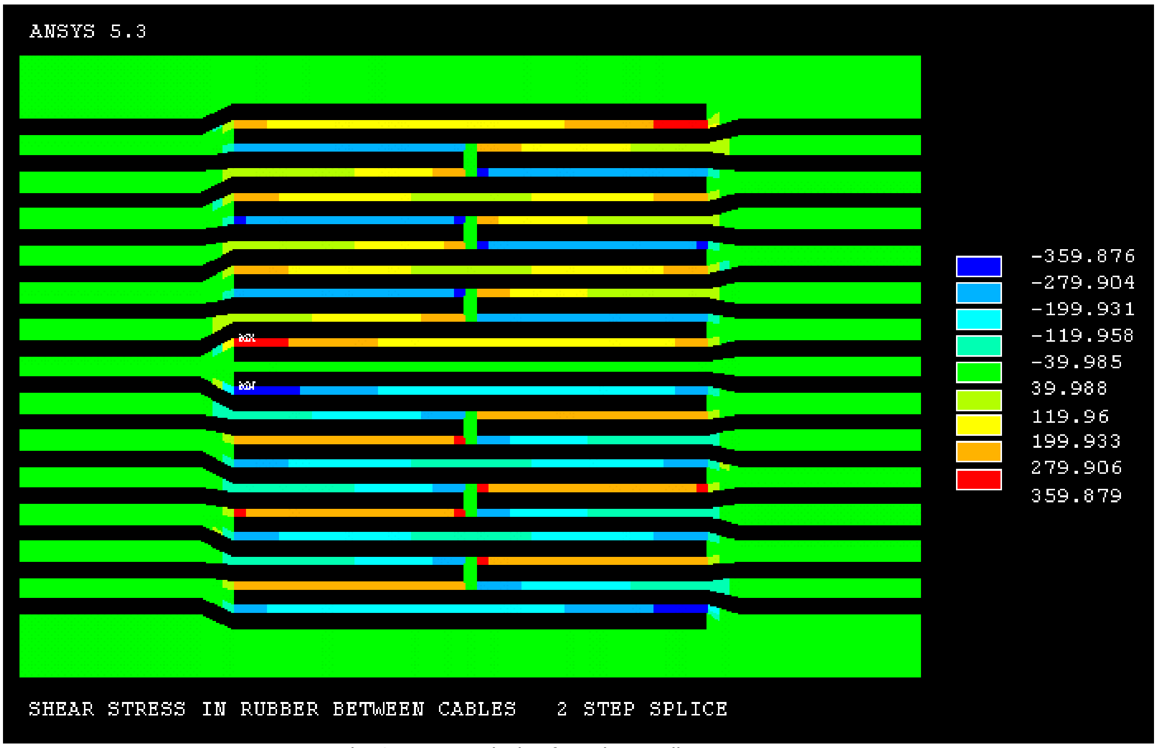


Fig. 25 FEA analysis of test loop splice pattern

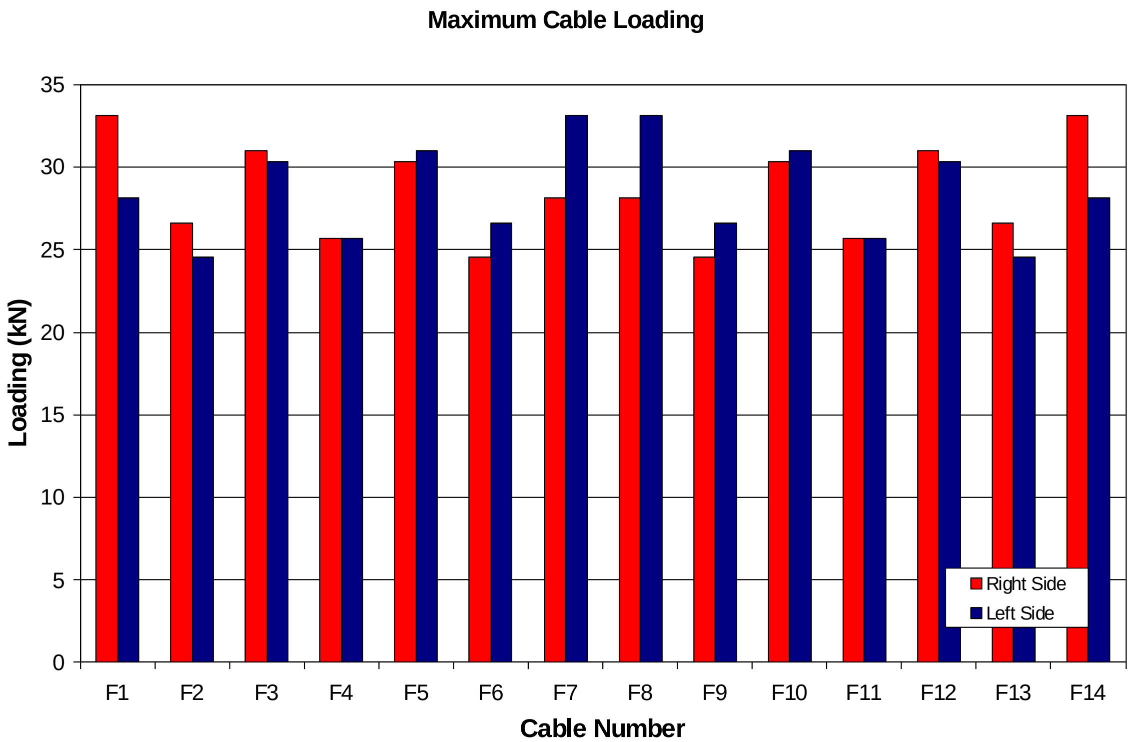


Fig.26, Cord load distribution with 60% of break load applied

Dynamic splice efficiency is defined in DIN 22110-1991 (Part 3) in terms of the reference fatigue strength at 10,000 load cycles. Per the standard, a load cycle is a 50 second saw-tooth shaped load applied to the test loop between 6.6% and, in this case, 60%, Fig. 27.

New splicing techniques developed for high tension splices were applied to the original splice pattern which had proved reliable during the service life of the original belt.

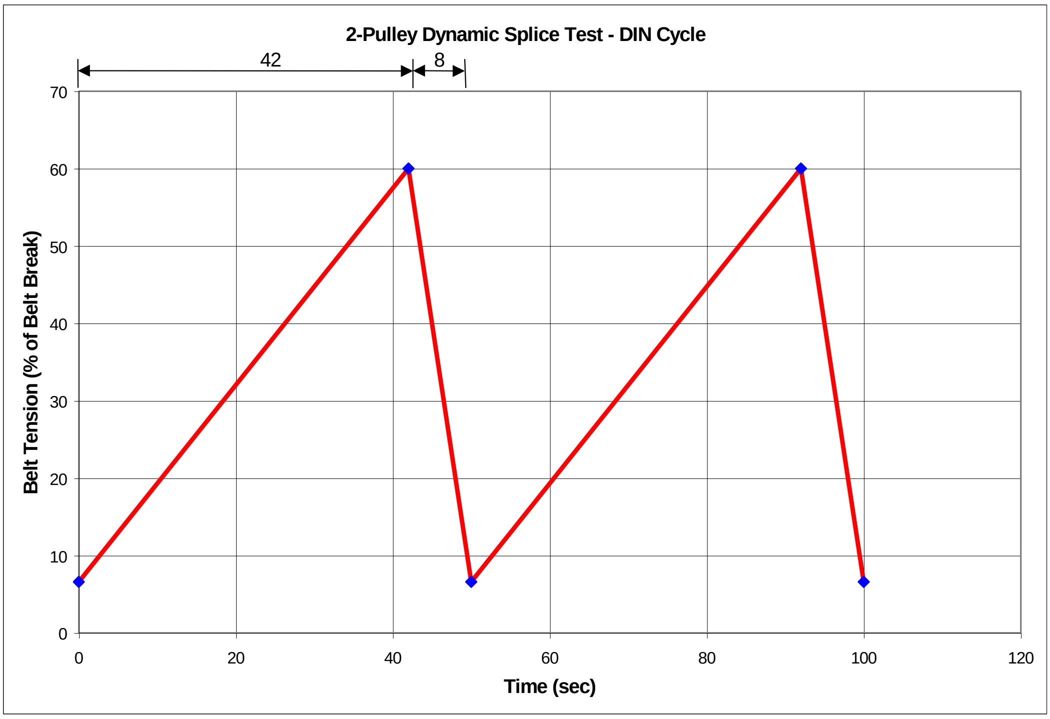


Fig. 27 DIN 22110 Part 3 Dynamic splice test load cycle

Two splices were tested; one at 60% and another at 50%. Fig. 28 shows the elongation versus load cycles characteristics for these two splice tests which are typical for the test. The test at 50% load was terminated at 30,000 cycles. The test at 60 % stopped at 25,735 load cycles when the belt broke 30 ft ahead of the splice. Figure 29 shows a predictive fatigue curve based on the two results and a third point of 100% at 1 load cycle. From this curve it is possible to assess a reference fatigue strength for the splice at 10,000 load cycles of approximately 63%.

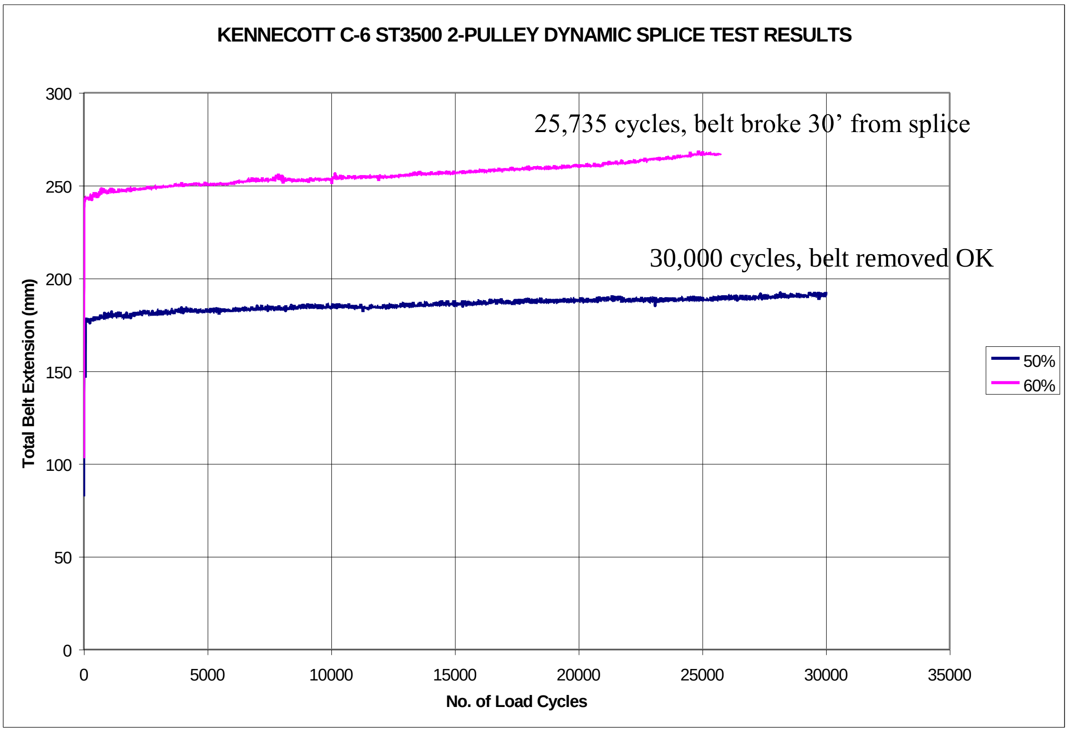


Fig. 28 2-Pulley dynamic splice test extension data for Kennecott C-6 belt at 50% and 60% load

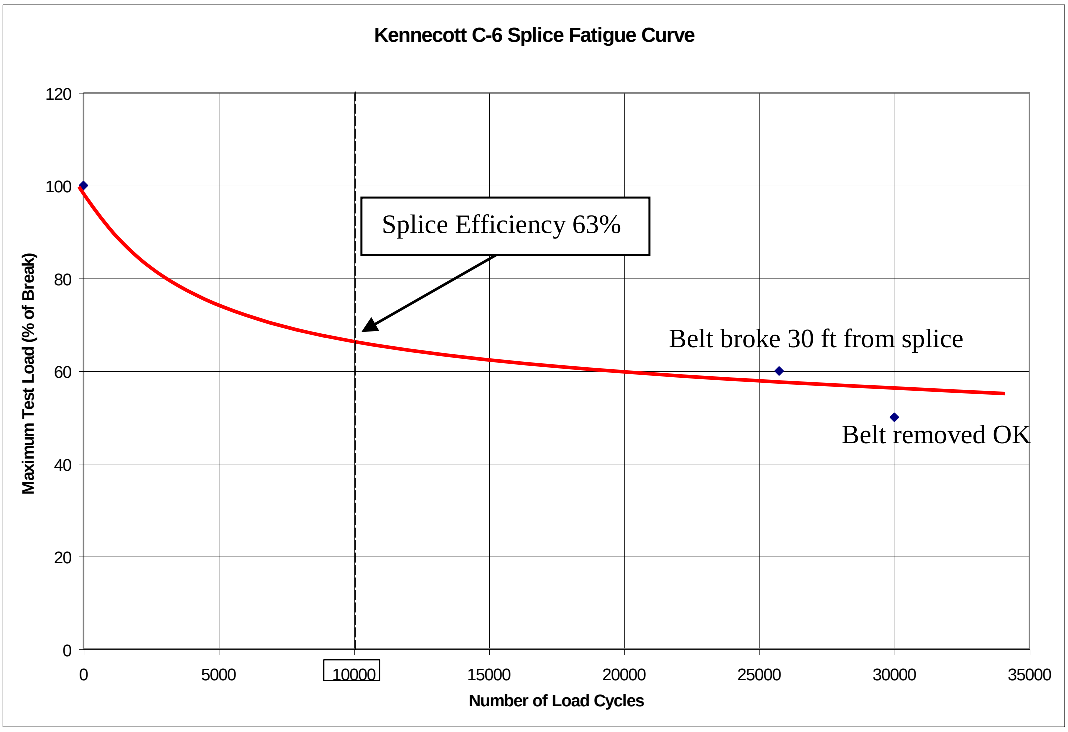


Fig. 29 2-Pulley dynamic splice test fatigue curve for Kennecott C-6 ST3500 belt

FIELD APPLICATION OF SPLICES

The original C-6 belt was replaced in August 2002 by National Belt Services from Biormingham, Alabama. The new belt was reefed out and spliced ahead of the change-out so as to minimize the mine downtime. A custom 35 page Splice Specification was written defining the splice pattern, materials, methods, work area, tools, quality assurance standards and daily report sheets. The purpose of the Splice Specification was to provide Kennecott with a document that would serve both as a basis for bids from splicers and also provide them with sufficient information to enable them to monitor and assess the quality of the splices in progress should they choose to do so.

Five of the twenty-four splices were made using a patented Splice Preform instead of the conventional insulation gum noodles. The insulation gum preforms reduce splice time by reducing cord lay-up time and cement drying time. They also provide improvements in cord spacing and alignment and this has shown to improve dynamic splice life. Fig. 30 shows preform material as supplied to Kennecott. The final splice was also made using preforms as the preform splice is made without the use of cements and there was a concern about dust sticking to wet cement because the final splice was made on the conveyor instead of the splice shed.

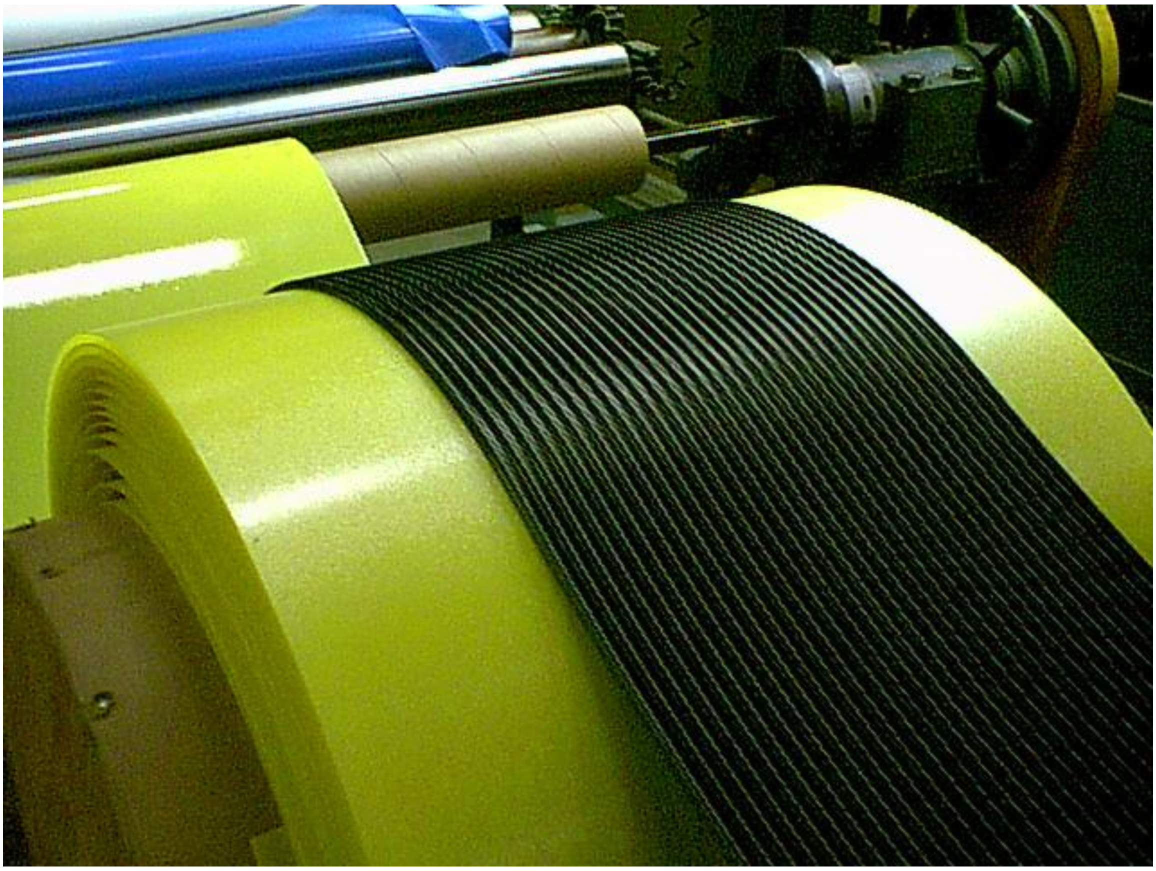


Fig. 30 Patented splice preform material for C-6

REPLACEMENT BELT SHIPPING

Fig. 31 shows two of the twenty-four belt rolls of the replacement belt on a rail-car ready to ship to the mine site. The steel shipping reel's design provides good support and protection for the belt during shipping and storage. The same reel design had successfully protected a similar diameter but narrower belt from damage after it fell from a truck on a curve during transportation.

Fig.31 Two rolls of replacement belt ready to ship to Kennecott February 2002

CONCLUSIONS

Kennecott’s investment in an in-pit crusher and a conveyor system to move the material through a tunnel in the pit wall has proved to be a successful innovative idea. The conveyor system, which is the lifeline for the mine, was successful due to good system design, careful belt selection, a reliable belt rip protection system and good, disciplined conveyor maintenance.

After almost 14 years of service, the most critical belt, a 72” ST3500 on C-6, was removed after exceeding all warranty expectations. In particular, it exceeded warranty life by 40% and warranty tonnage by 245%. The belt was finally replaced due to the convenience of system downtime created by a crusher move and because of the awareness of the increasing incidence of cord damage/breaks. Belt top cover wear was less than 40% of the original gauge and pulley cover wear was negligible.

Periodic field measurements of cover wear and non-destructive scans provided valuable data to the mine on the belt’s condition and ultimately this data permitted the mine to plan the belt’s replacement to coincide with their required crusher move. This was facilitated by the belt manufacturer’s criteria for assessing a belt’s condition.

Laboratory testing on the old belt indicated that the belt physicals, with the exception of cover to insulation adhesion, compared well with the same belt when new and are close to the original specification values. Even this lower value was more than adequate for years of continued service.

During the life of the belt embedded rip protection sensor loop design of the rip protection system was improved after studying non-functioning loops.

The replacement belt was successfully shipped by rail in 24 rolls mounted on special protective steel reels.

A dynamic splice fatigue requirement of 60% was tested and exceeded using the original splice pattern and new splicing techniques developed for high tension splices.

A 35 page custom splice specification was developed for the customer to use for both splice bidding and also as a tool to monitor splice quality. This provided detailed work instructions for the field splicers and provided an aid to ensure splices were made consistently and to the same high standard as the test splices. Belt supplier splice supervision was also provided.

Conveyor downtime was minimized by reefing the replacement belt and splicing it prior to installation. Splicing was successfully performed by National Belt Service from Birmingham Alabama in an off-line splice house with the last splice being made on the conveyor. Splice insulation gum preforms were used in place of conventional noodles on five of the twenty-four splices and achieved time savings and improved splice quality. The last splice was made on the conveyor and splice preforms were successfully used to reduce the possibility of dust contamination due to the no-cement construction of this splice.

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ABOUT THE AUTHOR

Dr. Robin Steven holds a BSc and PhD in Mechanical Engineering from the Queens University of Belfast, Northern Ireland. He has worked for The Goodyear Tire & Rubber Company Engineered Products Division since 1974. During his time with Goodyear he has worked in several product areas including hose, power transmission and conveyor belts. He also has experience working for several years in Goodyear plants around the world including Northern Ireland, South Africa, Brazil and the United States. He is currently Project Engineer and Team Leader of Goodyear’s Flexsteel steel cord conveyor belt group based in Marysville, Ohio, USA.

Robin B. Steven
Project Engineer
Industrial Products Division
The Goodyear Tire and Rubber Co, Ltd.
13601 Industrial parkway,
Marysville Ohio, USA

Tel: 937 644 8909
Fax: 937 644 8937
E-mail: robin_steven@goodyear .com

NOTES:

18 March 2003 A steel plate fell onto return side of C-6 conveyor and got caught in the tail pulley. It ripped 80 ft of belt before the rip protection system shut them down.