Flammability of wider conveyor belts using large-scale fire tests

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Abstract

The Mine Improvement and New Emergency Response Act of 2006 (MINER Act) established a Technical study panel (the Panel) to provide recommendations on the utilization of belt air and new technology that may be available for increasing the fire resistance properties of conveyor belt used in underground coal mines. The Panel Report recommended use of the belt evaluation laboratory test (BELT) as the method for testing and approval of flame resistant conveyor belts used in underground coal mines. The research conducted to establish the correlation of the BELT with large-scale belt fire flammability tests was done using 91 - 107 cm (36- to 42-in.) wide conveyor belt. Due to today's coal haulage capacity, the mining industry is using 183 cm (72 in.) and wider conveyor belts. The U.S. National Institute for Occupational Safety and Health (NIOSH) conducted a study to determine if the BELT will also qualify wider belts as fire resistant for use in underground coal mines. This paper describes the results of recent experiments comparing results from using the BELT and the large-scale tests for six different belts.

Introduction

The 2G test, described in 30 CFR 18.65, has been used for acceptance of fire-resistant belting since 1955. The accepted method was mandated by the Federal Coal Mine Health and Safety Act of 1969 to qualify a belt as fire-resistant for use in underground coal mines in the United States. To conduct the 2G test, a 15-cm-long by 1.3-cm-wide (6 in. by 0.5 in.) sample of belt is exposed to a flame from a Bunsen burner in still air for one minute, with the transverse axis at 45° inside a 53-cm (21-in.) cubical test gallery. After one minute, the flame is removed, and the sample is exposed to air at a velocity of 91 m (300 ft) per minute. The belt passes the test if the flame duration is less than one minute for four samples of the same belt, or if the afterglow is less than an average of three minutes. In their report, the Technical Panel on the Utilization of Belt Air noted that the 2G test has various deficiencies, as seen in the persistence of belt fires in underground coal mines (Mutmansky et al., 2007).

The U.S. Bureau of Mines (USBM), in cooperation with the Mine Safety and Health Administration (MSHA), first addressed the use of the 2G test to evaluate conveyor belt fire resistance in laboratory-scale tests in the early 1980s (Sapko et al., 1981). Large-scale tests were conducted in the mid 1980s to compare the results of the 2G test to results in large-scale conveyor belt fire tests (Lazzara and Perzak, 1989). In this study, nine synthetic rubber belts and eight PVC belts were evaluated in full-scale fire tests in the Lake Lynn Fire Gallery. Of the 17 belts tested, 16 were rated as MSHA-accepted fire-resistant based on the 2G test. One belt was rated as non-fire-resistant. Of the 16 belts that passed the 2G test, 11 belts failed the Fire Gallery test criteria, exhibiting flame spread and belt damage beyond the ignition area, while five belts passed the test. Based on these results, the National Institute for Occupational Safety and Health (NIOSH) and MSHA worked to develop a new laboratory-scale test apparatus and method for evaluating the fire resistance of conveyor belts that more closely correlated with the results of the large-scale Fire Gallery results (Verakis, 1991; Verakis and Dalzell, 1988). Further research was completed comparing the apparent fire resistance of 21 conveyor belts based on tests conducted in the Fire Gallery and a new laboratory apparatus (Lazzara and Perzak, 1990). Of the 21 belts tested, the results showed that 19 were in full agreement based on the pass/fail criterion developed for the two test methods. Based on the results of the large-scale conveyor belt fire tests and new laboratory-scale test work, MSHA published a proposed rule in 1992 to replace the 2G test with this new laboratory method, belt evaluation laboratory test (BELT) (1992). In July 2002, the proposed rule was withdrawn. MSHA cited a significant decline in conveyor belt fires from 1993-2002, belt monitoring improvements, such as fire detection, and technological advancement, such as roller and bearing improvements to minimize friction on the belt, as reasons for withdrawing the proposed rule (MSHA, 2002).

The panel's report recommended the immediate implementation of BELT as the method for testing and approval of flame resistant conveyor belts (Mutmasky et al., 2007). However, since the correlations between the laboratory-scale tests and the full-scale tests used to establish the BELT method were based on 91-to-107-cm- (36-to-42-in.)-wide conveyor belts, NIOSH and MSHA decided to conduct experiments to determine if the correlation is still valid for the wider conveyor belts typically used in mines today. This report describes the

Figure 1 — Fire Suppression Facility.

Figure 2 — Gas burners.

Figure 3 — Shield for gas burners.

results of experiments conducted on a number of wider belts using the laboratory-scale BELT method and large-scale tests in the NIOSH Fire Suppression Facility.

Belts evaluated

The conveyor belting chosen for this research was purchased as brand new conveyor belting from each manufacturer. Each belt is 183 cm (72 in.) wide. The goal in choosing the conveyor belts was to evaluate different types of belts used in the mining industry in the U.S. and other countries today. Three different types of belt material were selected: polyvinyl chloride (PVC), styrene butadiene rubber (SBR) and chloroprene. Three of the belts meet three different U.S. standards, non-fire resistant, 2G-accepted and BELT-approved. The three other belts meet foreign fire resistance standards (Australian, British and German). Table 1 shows the type of belt material, standard approval, construction, strength and cover dimensions.

Table 1 — Conveyor belts evaluated.

	Belt	Standard	Ply	Strength, piw[7]	Covers
1	N[1]	Australian	3	600	3/16 x 1/16 in.
2	PVC[2]	British	SW[6]	800	2 x 2 mm
3	SBR[3]	NFR[5] US	4	800	3/8 x 3/32 in.
4	SBR[3]	2G US	3	600	3/16 x 1/16 in.
5	SBR[3]	BELT US	3	600	3/16 x 1/16 in.
6	C[4]	German	3	600	3/16 x 1/16 in.

[1] Neoprene
[2] Polyvinyl chloride
[3] Styrene butadiene rubber
[4] Chloroprene
[5] Non-fire-resistant
[6] Solid woven
[7] Pounds per inch of belt width (widely used in the U.S.)

Experimental description

Large-scale test. The large-scale fire tests were conducted at the NIOSH Fire Suppression Facility (FSF). The FSF, shown in Fig. 1, is a full-scale, state-of-the-art fire test facility located on the surface at the Lake Lynn Laboratory in Fairchance, PA. The fire tunnel is configured in a T shape to simulate a main mine entry and crosscut. The main entry is 47 m (153 ft) long and the crosscut is 12 m (40 ft) long. For these experiments, the crosscut was closed off. The entry is 5.5 m (18 ft) wide by 2 m (7 ft) high. The FSF is equipped with a 1.8-m- (6-ft)-diameter, variable speed axial vane fan, located at one end of the main tunnel to provide ventilation. The fan has a pneumatic controller to adjust the fan pitch in order to increase or decrease the air velocity.

The FSF is equipped with a nine-point gas monitoring array at the open end of the tunnel to measure the gas components produced from a belt burn test. The array is made of 1.3-cm (0.5-in.)-diameter black steel pipe positioned at the center of the entry. A total of nine 0.3-cm (0.125-in.) holes are drilled into the vertical section of the pipe to sample the gases. The sample holes are equally spaced vertically from the roof to the floor. A 1.3-cm (0.5-in.) tube is connected to the steel pipe and leads back to the control room to a set of infrared gas analyzers. The gas analyzers measure carbon monoxide (CO), carbon dioxide (CO_2) and oxygen (O_2) gas concentrations. The gas data was collected every two seconds and was recorded by a computer-based data acquisition system.

A nine-point thermocouple array was also located at the open end of the tunnel to measure the average exit gas temperature for use in heat release rate calculations. The thermocouples are attached to three vertical half-diameter steel pipes spaced evenly across the width height of the entry. The heat release rate for each test is computed using the exit gas temperature by the following equation:

$$Q_{total} = C_p \times \varrho_o \times V_e \times A_o \times \Delta T \qquad (1)$$

where Cp = heat capacity of air, 1.088 x 10^{-3} kJ/g °C
ϱ_o = density of air, 1,200 g/m^3
V_e =average exit air velocity, m/s
A_o = entry cross section area, m^2
ΔT = average exit temperature – initial temperature, °C.

The FSF was equipped with two video cameras to record each test burn. The first camera is mounted in the center of the roof, roughly 18 m (60 ft) from the fan, to give a frontal view of the conveyor belt structure during the test. The second video camera is

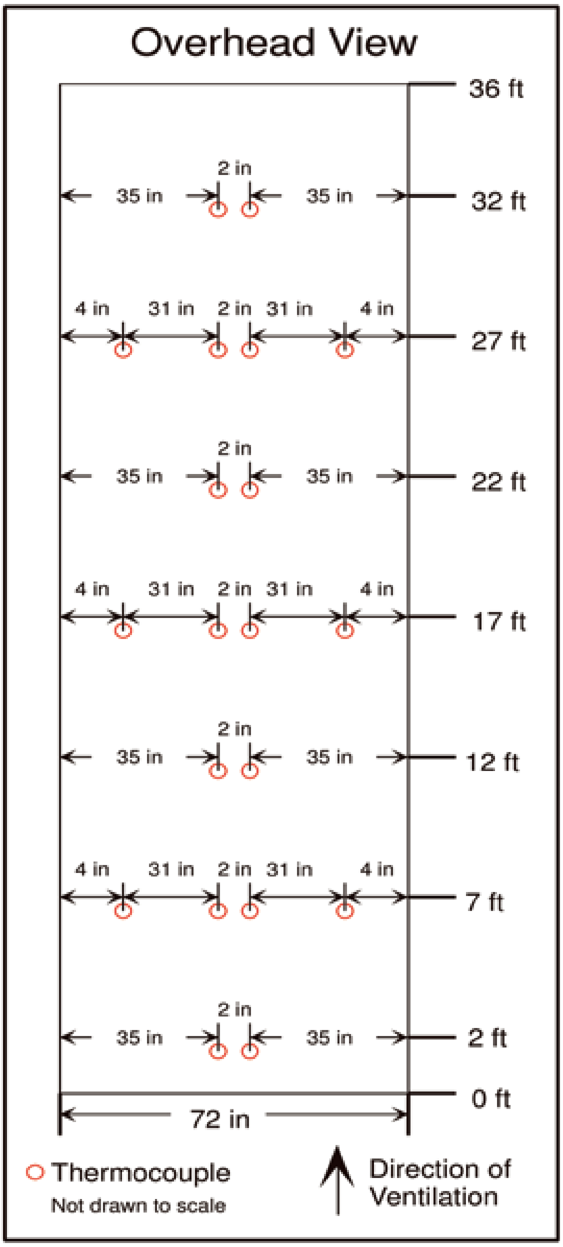

Figure 4 — Thermocouple layout.

placed on the left side of the tunnel, facing the open end of the tunnel, upstream from the conveyor belt structure, to view the underside of the conveyor belt at the point of ignition. The conveyor belt structure is located 26 m (85 ft) from the fan and is slightly off center of the entry to allow for heavy equipment to pass on one side to place the belting onto the structure. The conveyor belt structure is 15 m (50 ft) long and 2.2 m (7.25 ft) wide. The trough idlers are 13 cm (5 in.) in diameter and are placed at 1.5-m (5-ft) intervals.

To ignite the belt, four sets of natural gas impinged jet burners, connected in series, were placed in front of the belt structure, as shown in Fig. 2. Each burner was equipped with 60 stainless steel jets, having a combined rated output of 44 to 114 kilowatts per burner. The ignition region was confined by metal shields on the front, left and right sides, and the top to form a box around the ignition zone to reduce the effects of the ventilation on the ignition process, as shown in Fig. 3. The back side was unshielded towards the open end of the fire tunnel.

Figure 5 — BELT test apparatus.

To conduct a test in the FSF, a 11-m- (36-ft)-long piece of conveyer belt is installed on the conveyor belt structure. The upstream end of the belt is affixed to the burners by metal wire, as shown in Fig. 2. Thermocouples are installed on the center line of the belt at 1.5-m (5-ft) intervals and along the two edges of the belt at 3-m (10-ft) intervals, as shown in Fig. 4. The first row of thermocouples are placed 0.6 m (2 ft) from the front of the belt in the ignition zone. Each thermocouple is placed just below the surface of the belt to measure the belt temperature and determine when the flame reaches that distance on the belt.

The air velocity is defined as the airflow over the top center of the belt, 5 m (17 ft) beyond the ignition zone and 0.3 m (1 ft) above the surface of the belt. The velocity measurement is made using a handheld vane anemometer. The pitch of the fan blade is varied to achieve the desired air velocity. Air velocity measurements are also made at the thermocouple and gas points at the exit of the tunnel, 46 m (150 ft) from the fan. The exit air velocities at each point are averaged together and recorded as the exit air velocity. It is important to mention that once the air velocity was set for the test, at no time was the fan turned off or adjusted until the test was completed.

To ignite the belt, the four sets of natural gas burners are placed 1.37 (4.5 ft) in front of the structure, the belt is secured over the gas burners with metal wire and the gas burners are ignited with a propane torch. The natural gas is allowed to flow for 10 minutes before it is turned off. The belt is allowed to burn until it is just smoldering, with no visible flame, or until the entire length of the belt is consumed by the fire. The belt passes the large-scale test if, in two separate trials, there remains a portion of the belt across the entire width that is not damaged. A belt fails the test if, during any of the two trials, the belt burns completely to the end.

BELT apparatus. The USBM, in cooperation with MSHA, developed a laboratory-scale flame test known as the BELT test to address the deficiencies of the 2G test. The BELT test can be conducted in a relatively simple laboratory setting and does not require a full-scale fire gallery. The BELT apparatus is a 1.68-m- (5.5-ft)-long by 0.46-m- (1.5-ft)-square, 2.5-cm- (1-in.)-thick ventilated tunnel made of refractory material. Round stainless steel ducting is used to exhaust the fumes produced from the burning of the belt. A steel rack made of slotted angle iron is used to hold down the belt during the test, as shown in Fig. 5. To ignite the belt, an impinged jet methane gas burner containing two rows of six jets is used. The methane used is technical grade 2 (99.99%).

To conduct a BELT test, a belt sample is cut to the size of 1.5 m by 23 cm (5 ft by 9 in.). The belt is fastened to the

Table 2 — Flame spread rates.

	SBR 2G Belting			
Ventilation rate (ft/min)	200	400	500	600
Flame spread rate (ft/min)	11.2	14.6	11.5	13.8

Table 3 — Large-scale test results.

	Type	Standard	Flame spread rate ft/min	Peak fire size management	Belt damage, ft	Pass/ Fail
Belt 1 T1	Neoprene	Australian	NA	0.22	2.5	P
Belt 1 T2	Neoprene	Australian	NA	0.30	6	P
Belt 2 T1	PVC	British	NA	0.15	less than 1	P
Belt 2 T2	PVC	British	NA	0.13	less than 1	P
Belt 3 T1	SBR	non fire-resistant U.S.	flashover	10.00	36	F
Belt 3 T2	SBR	non fire-resistant U.S.	flashover	11.00	36	F
Belt 4 T1	SBR	2G U.S.	14.6	6.00	36	F
Belt 4 T2	SBR	2G U.S.	21.0	9.00	36	F
Belt 5 T1	SBR	BELT U.S.	NA	0.12	1	P
Belt 5 T2	SBR	BELT U.S.	NA	0.09	less than 1	P
Belt 6 T1	Chloroprene	German	NA	0.14	2	P
Belt 6 T2	Chloroprene	German	NA	0.13	2	P

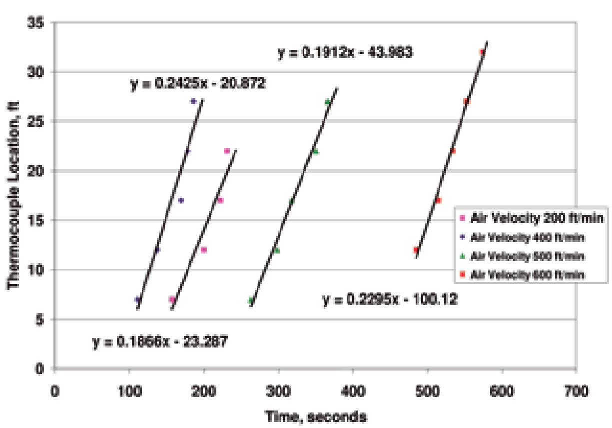

Figure 6 — Plot of flame spread rates of 2G-accepted SBR belting.

angled iron rack, cover side up, using cotter pins and washers to prevent it from shrinking away from the burner. The front of the rack is then placed and centered 15 cm (6 in.) inside the tunnel. The ventilation for the tunnel is set at 61 m (200 ft) per minute using a vane anemometer to measure the air flow. The belt is ignited by applying the methane burner to the front edge of the belt with the flames distributed evenly over the top and bottom. The flow of methane to the burner is set at 0.034 ± 0.1 m^3/min (1.2 ± 0.1 cfm). The methane burner is removed after five minutes and the belt is allowed to burn until the flames are out. The belt passes the test if in three separate trials there remains a portion of the belt across the entire width that is not damaged. A belt fails the test if during any of the three trials the belt burns completely to the end of the sample (MSHA, 2008).

Results and discussion

Large-scale test. Initially, tests were conducted using the 2G-accepted SBR belt at air flows of 62, 122, 152 and 183 m (200, 400, 500 and 600 ft) per minute to determine the worst-case air velocity. This belt was chosen because it is commonly used in the U.S. coal mining industry. To calculate the flame spread rate, the time and distance were recorded when the fire reached each row of thermocouples. The points were then plotted on a graph and the data was fitted by linear regression. The slope of the line is the flame spread rate. The results are shown in Fig. 6 and Table 2. The results indicate that the worst-case air flow is 122 m (400 ft) per minute. The plots in Fig. 6 show that the flame spread rate is linear over the 11-m (36-ft) length for each of the air velocities.

After determining the worse case air flow of 122 m (400 ft) per minute, this ventilation rate was used to evaluate all six belts in the large-scale test. Two tests were conducted for each belt. As mentioned earlier, the pass/fail criterion is based on the damage to the belt. A belt passes the large-scale test if, in two separate trials, there remains a portion of the belt across the entire width that is not damaged. A belt fails the test if, during any of the two trials, the belt burns completely to the end. The flame spread rate was calculated for the belts that burned out of the ignition zone. The peak fire size is the optimum heat release rate after the gas burners are turned off. The damage to the belt was recorded as the length of belt burned away from the gas burners. The flame spread rate, peak fire size, amount of belt damage and pass/fail results are shown in Table 3.

The Neoprene, PVC, chloroprene and BELT-approved SBR belts (belts 1, 2, 5 and 6) passed the large-scale test based on the stated criteria. These belts did not burn out of the ignition zone and were unable to reach steady-state flame propagation. The peak fire size these for belts ranged from 0.09 and 0.12 megawatts (MW) for the SBR belt to 0.22 and 0.30 MW for the Neoprene belt. The small fire size was due to the small amount of belt burned in each test. The worst belt damage was observed for the Neoprene belt that meets the Australian

Table 4 — BELT Test results.

	Type	Standard	Pass/fail
Belt 1	Neoprene	Australian	P
Belt 2	PVC	British	F
Belt 3	SBR	non-fire-resistant U.S.	F
Belt 4	SBR	2G U.S.	F
Belt 5	SBR	BELT U.S.	P
Belt 6	Chloroprene	German	P

standard, which burned 0.76 and 1.83 m (2.5 and 6 ft) in the two tests, while the SBR and chloroprene belts burned 0.61 m (2 ft) or less.

The non-fire resistant and 2G-accepted SBR belts (belts 3 and 4) failed the large-scale test. The non-fire resistant belt flashed over, setting the entire belt on fire at once, causing damage to the thermocouples, so no flame spread rate could be obtained. The non-fire resistant belt burned completely to the end of the sample. The 2G-accepted SBR belt flame spread rate was 4.5 m (14.6 ft) per minute for the first test and 6.4 m (21.0) ft per minute for the second test. The peak fire size for the non-fire-resistant belts was 10.0 and 11.0 MW, while the peak fire size for the 2G accepted SBR belts was 6.00 and 9.00 MW.

BELT results. The results of the BELT tests are shown in Table 4. In this test, the Neoprene, BELT-approved SBR and chloroprene belts met the pass criteria. The PVC, non-fire-resistant SBR and 2G-accepted SBR belts failed.

Summary

Six different types of 183-cm- (72-in.)-wide conveyor belting that were deemed acceptable by different flammability standards were evaluated for fire resistance under large-scale test conditions. Full-scale fire experiments were conducted in the NIOSH FSF and the results were compared to the results of laboratory-scale BELT. Of the six belts tested in the large-scale tests in the FSF and the BELT apparatus, five of the belts produced similar results. The Neoprene, BELT-approved SBR and chloroprene belts passed both tests. The non-fire-resistant and the 2G-accepted SBR, as expected, failed in both tests. The PVC belt that meets the British standard passed the large-scale test, but failed the BELT test. In the case where the large-scale test results did not correlate for the one PVC belt, the BELT test provided a more conservative result. Although the test difference is not completely understood for the one PVC belt, a partial explanation may be related to lower concentration of the combustible atmosphere generated in the full-scale test and greater heat loss versus the BELT during the combustion process of the PVC belt. Overall, these experimental results indicate the BELT represents a reasonable correlation of the fire resistance characteristics of wide conveyor belting under full-scale fire conditions as tested in the FSF. Also, the experimental tests of the 183-cm- (72-in.)-wide belts in the FSF were comparable to the previous large-scale test results of the 91-107-cm-(36-42-in.)-wide conveyor belts conducted by the USBM. As the industry moves to even wider and thicker belts in the future, there will continue to be a need for large-scale experimental studies to ensure that the correlation between the BELT method and conveyor belt fire resistance is maintained.

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Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of NIOSH.

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