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TESTING OF FIRE-RESISTANCE OF MATERIALS USED IN CANADIAN MINES

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by

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ABSTRACT

A brief history of the testing of fire-resistance of conveyor belting in Canada is given. The various tests used for this purpose are described and analyzed using the results of research that have been carried out at CEAL during the past few years. The current tests carried out on hydraulic fluids are also described.

Key words: conveyor belting, flammability, fire-resistance, hydraulic fluids

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TESTS DE RÉSISTANCE AU FEU DE MATÉRIAUX UTILISÉS DANS LES MINES CANADIENNES

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RÉSUMÉ

Un bref historique est donné concernant les tests de résistance au feu effectués au Canada sur les courroies de convoyeur. Les différents tests effectués sont décrits et analysés par le biais des résultats de recherches entreprises par le LCRE ces dernières années. Les essais courants concernant les fluides hydrauliques sont aussi discutés.

Mots-clés: courroies de convoyeur, inflammabilité, réfractaire au feu, fluides hydrauliques

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INTRODUCTION

Modern society is increasingly dependent on synthetic polymeric materials in all areas, including underground mines. These materials offer many desirable properties. At the same time, however, they have the potential for increasing the risk to human life and of material damage due to fires.

Many companies have carried out considerable research to develop compositions that will decrease the chance of fire. Much research has been carried out throughout the world on developing test methods that properly evaluate the tendency of materials to burn under different circumstances. Many countries have introduced regulations governing the use of non-metallic materials in mines.

My talk today will discuss the research on test methods that we have been carrying out at the Canadian Explosive Atmospheres Laboratory during the past few years. The work has been primarily in support of developing National Standards for various materials. As I hope to be able to show you, test methods are not always based on scientific principles. Sometimes the tests can give a false sense of confidence.

Why are we interested in this subject? The first slide, a clipping from our newspaper, which reports on a disastrous fire in a Japanese mine, provides the answer.

Fires in underground mines are particularly dangerous because the avenues of escape are limited. Fires in aircraft, spacecraft and ships are also dangerous for similar reasons. You may recall the American astronauts who died in their spacecraft while it was still on the ground. In that case, the designers seemed to have been insufficiently aware of the increased flammability of materials in an enriched oxygen atmosphere. Canada has not been immune from disasters caused by the flammability of materials. Many people died in a fire on a Canadian jet a couple of years ago. In that case, the toxicity of the gases from the combustion process caused the greater proportion of deaths. Not long ago, there was a major disaster in a mine in South Africa. The polyurethane foam that was sprayed on the walls as an insulator to keep the mine from getting too hot caught fire and the gases produced by the fire spread too quickly to escape from.

In mines, combustible materials include conveyor belting, brattice cloths, ventilation tubing, insulation on wires, hydraulic fluids, pipes for methane drainage and water supply, etc. Most of our work has been on conveyor belting, because of the large amounts used and because of the possibility that the conveyor belt can cause a fire to be spread a long way from its source.

THE CANADIAN EXPLOSIVE ATMOSPHERES LABORATORY

I would first like to show you our laboratory. There are 14 people in all, consisting of 4 scientists, 3 engineers, 6 technologists and a secretary. The laboratory is responsible for certifying electrical equipment for use in underground coal mines and for certifying various materials for use in all underground mines. It is also responsible for carrying out tests on electrical equipment for hazardous environments, in applications other than mines. During the past few years, it has gained a world-wide recognition for its work on diesel emissions, particularly in underground mines. Recently, a programme of research has begun in the field of dust explosions.

THE CANADIAN APPROACH TO THE PROBLEM

Canada is a federal country, an aspect of which being that the individual provinces, rather than the national government, have the legal authority to regulate the mines in their provinces. Because we are a relatively young country, a significant portion of the capital investment and managers and engineers have come from abroad. Hence, we are strongly influenced by countries with longer traditions and our rules and standards reflect this.

Before the establishment of the laboratory, the provinces required that electrical equipment for coal mines have a certificate from another recognized testing authority, usually the National Coal Board of the U.K. This system placed any potential Canadian manufacturer who wished to sell locally at a disadvantage. Therefore, our laboratory, which is an agency of the federal government, was established some 35 years ago on the request of the provinces.

At the beginning, our laboratory adopted the Standards either of England or the United States. Gradually, however, some of the tests were changed so that they suited Canadian requirements. One of the problems, however, was that these changes were made on a unilateral basis.

In addition, many of the provinces were still accepting materials certified according to the foreign standards. Thus, the realization came that Canadian standards were required. A nonprofit, nongovernmental agency, the Canadian Standards Association, organized the committees that have written the Standards.

Each Technical Committee is responsible for one type of product, and is composed of representatives of users (the mines), manufacturers, government (regulatory agencies), insurance companies and any other interested party. Each committee relating to mining materials has a representative of our laboratory who plays a key role in developing the Standard, including carrying out research in support of it.

These Standards Committees have representatives from other countries in cases where those countries are important to Canada. For example, of the 20 members on the conveyor belting committee, 4 of the members represent foreign interests - 2 are English, 1 American and 1 from the Japanese Belting Association. In this way, we have direct access to the foreign countries so that we can develop standards that are truly world class. The Standards take several years to develop, because of the conflicting interests of the different members and the time required to carry out research to resolve technical issues.

As some of you know, there exists the International Standards Organization (ISO) which attempts to write internationally-acceptable Standards. Unfortunately, due to the compromises required to achieve an international standard, the standards may sometimes not be strict enough to provide adequate safety, as in the case of conveyor belting (ISO 340).

CONVEYOR BELTING

FLAME TEST

A small-scale flame test may seem to be a very easy test to perform and obtain reproducible results. All one has to do is apply a flame to a small sample of the material and observe how long the flame or glow takes to disappear. Unfortunately, the results obtained are not very reproducible, not only when comparing from one laboratory to another, but even when the same person does the test on the same equipment. The flame test that has been used by CEAL for many years was copied from that used by the United States Bureau of Mines. It is shown in the slides.

Although the CEAL apparatus resembles the U.S.A. apparatus, the method of carrying out the test has the result of making Canadian-approved conveyor belting much more fire-resistant than U.S.A.-approved belting. The major differences are:

1. Canada tests in both still and flowing air; the U.S.A. tests only in flowing air. The still air test is more severe for measuring flameout time; the flowing air test is more severe for measuring afterglow time.

2. Canada uses a flame with a blue inner cone 25mm high; the U.S.A. uses a flame with no inner cone (the flame is defined as 3 inches high). At the point where it impinges upon the sample, the Canadian flame is about 1100°C; the U.S.A. flame about 760°C.

3. The U.S.A. uses a sample holder holding a 150mm long sample by its end. During the tests, the sample often loses its rigidity, and may lose proper contact with the flame. To eliminate that problem, Canada has been using a metal holder that the sample rests upon, with only 25mm of the sample projecting beyond it. But, solving one problem often creates another: sometimes the metal holder acts as a heat sink to quench the fire burning in the sample. We have now redesigned the sample holder to achieve a compromise in which the sample has adequate support, but no problem exists with quenching.

We have encountered another problem caused by the language of the requirement of the test: because of wording a very flammable belting could have been said to have "passed" this test! A company submitted a used conveyor belting that they had coated with polyurethane. The flame did go out in less than a minute, as required by the test -- the reason being that the entire sample had burnt! Despite meeting the formal requirements of the flame test, the product was not certified, because it did not meet the antistatic requirements.

The main problem with this test is the lack of reproducibility. My technician and I carried out, independently, tests on two particular beltings - a rubber type and a PVC type - over a period of a whole year in order to test the reproducibility (Table 1). The standard deviations of each set are rather high; more importantly, the means of each set vary drastically. We have not determined the cause of the set-to-set variability, but suspect that the test is very sensitive to small changes in the positioning of the sample and flame.

Another area of concern is the reproducibility of tests between different testing laboratories. After working with the U.S.A. Mine Safety and Health Administration, we were able to achieve reasonable agreement on the flameout times on most samples.

Different countries use different flame tests. Unfortunately, the correlation between tests on the same product may be quite poor. The graph (Fig. 1) shows that the flameout times obtained by the National Coal Board test cannot be predicted from the results of the Canadian test ("modified MSHA test") - the scatter around the best-fit line is very large. Note that the slopes of the two lines are different as well, which indicates that different products react differently to the two tests. In other words, one cannot use the results of one country's flame test to predict if the product will pass another country's test.

DRUM-FRICTION TEST

Another test used in England, Canada and other countries is the drum-friction test. The objective is to simulate the situation in which a belt is stalled on a rotating drum. The drum continues to rotate and generates heat in the belting. If the belting becomes hot enough, it may burst into flames. A "stalled belt" appears to be the most common cause of conveyor belt fires in mines.

The test is conducted by clamping the belt in place and attaching a weight to one end of the sample. The drum is rotated at a constant speed until the belt breaks, or a certain period passes. If the belt breaks without showing any signs of flame or glow and the temperature of the steel drum surface in contact with the belt does not exceed 325°C, then it passes this test. Some tests are also carried out with a stream of air flowing against the drum, because the fresh air can stimulate glow in the sample. It is important to define the dimensions of the drum, because the results of the test depend on the rate of heat transfer.

PROPANE GALLERY TEST

There is now general agreement that small-scale flame tests cannot be expected to predict the actual performance of conveyor belts in a real mine fire. It is necessary to have a test above a certain critical size in order to decide if a belting is safe for use in a mine. Such a test is the propane gallery test. The size of the sample used in Canada is 0.9m by 4m. The propane burner consumes propane at the rate of 130g/min and produces a very substantial fire. It requires considerable work to conduct the test; the clean-up after the test is a very messy job. To pass the test, the sample immediately above the burner can burn, but the fire cannot propagate to the end of the sample. The idea is to ensure that a fire on a belt - the cause is not relevent - will not spread throughout a mine.

The main test parameters are: afterburn time, length of sample undamaged, temperature of exhaust and the total heat input. We have carried out many tests and have determined that the only reproducible parameter is the minimum time that the burner must be left on in order to achieve propagation. (Burner time is proportional to the total amount of heat input into the sample). We have found that each product has a critical burner time which is reproducible. Unfortunately, it is impractical to carry out sufficient tests to determine this critical burner time for each product submitted for certification.

The appropriate time that the burner should be left on is a matter of some controversy. The original method specified 10 minutes. We have found that some belts will "pass" at 10 minutes but 11 minutes will produce a self-propagating fire. I think, therefore, that for the ultimate test of fire-resistance, the burner should be left on until the material above the burner has burnt completely.

The parameter that we have chosen to indicate the magnitude of the fire during the test is the temperature at the exit of the chamber. Figure 2 shows the different tests carried out on the same sample but with different burner times. In curve "A", the fire goes out immediately after the burner is removed. In curve "B", the temperature decreases after the burner is removed and the fire can be seen to diminish in intensity; however, after a latent period, the fire increases in intensity and starts propagating. This type of burning behaviour has actually been reported in mine fires. In curve "C", the fire starts to propagate while the burner is still on.

Although the propane gallery test can be considered as being of laboratory-scale, the fire produced is of sufficient magnitude that we pay considerable attention to the safety aspects of conducting the test. Several years ago, a propane gallery facility in England burnt down during a test. These circumstances enable laboratory personnel to appreciate how a miner feels when a conveyor belt ignites.

HOT-PLATE TEST

You will recall that I showed that the flame tests have limited usefulness. Our laboratory has devised a minimum surface ignition temperature test which we call the hot-plate test. It is a small-scale test which does not require elaborate or sophisticated equipment. A stainless steel plate which is resistant to high temperatures is heated in a muffle furnace, then allowed to cool slowly. A thermocouple is placed in a hole drilled in the middle of the plate just below the surface. A small square of sample is placed on the centre of the plate just above the tip of the thermocouple and the time required for the sample to ignite is measured. Figure 3 shows a typical graph of time to ignition vs. temperature. At the highest temperature, the sample bursts into flames almost immediately. Below a certain critical temperature, the sample does not burst into flames, but just combusts. Figure 4 shows similar curves for a number of different samples.

CRITICAL OXYGEN INDEX TEST

Another small-scale test that we are working on is the critical oxygen index test. It measures the minimum percentage of O_2 in a flowing O_2/N_2 stream that will keep the sample burning. It is widely used for plastics but has not been used much for composite materials such as conveyor belting, because unreproducible results have been obtained. We have studied the parameters of the test to learn how to obtain reproducible results. The most important parameter is the sample width. Other researchers have used a sample width of 5-10mm. Figure 5 shows that the oxygen index is very sensitive to small variations in width in this range. Therefore, it is not surprising that unreproducible results are obtained. We have selected a 25mm width, based on this data.

Earlier in this lecture, I showed how the flame test varied widely in tests carried out over a year. At the same time, we carried out oxygen index and hot-plate tests on the same samples. Tables 2 and 3 show that both these tests do provide reproducible results. Therefore, they are more suitable for use as quality control tests than are the flame tests.

Table 4 shows a comparison of results using the different tests. As mentioned earlier, the propane gallery test is difficult and expensive to carry out, particularly for product development. We have devised a scheme to help manufacturers develop products to meet the propane gallery test by carrying out screening tests using the small-scale tests. If a product performs well on all the small-scale tests, then, the chances are good that it will pass the propane gallery test. This scheme has already been used successfully by one Canadian conveyor belt company.

ELECTRICAL SURFACE RESISTANCE TEST

In addition to flammability tests, we are also concerned with the possibility of the conveyor belt generating a static electrical charge of sufficient magnitude to ignite a methane/air mixture in a coal mine. We use a method copied directly from the National Coal Board of England, which measures the resistance between two electrodes placed on the surface of the belting. Recently, we have carried out a study on the effects of humidity and temperature on the surface resistance of conveyor belting. The results were very surprising: the surface resistance of PVC belts increased very rapidly with decreasing temperature. Although they were safe at 20°C, they became unsafe at 10°C. Rubber belts, on the other hand, increased in surface resistance very slowly with decreasing temperature.

HYDRAULIC FLUIDS

The two flammability tests that we carry out on fire-resistant hydraulic fluids are the wick test and the spray-ignition test. The wick test consists of soaking a nonflammable wick in the fluid and applying a flame to it. The spray-ignition test simulates a leaking high-pressure hydraulic fluid hose. The fluid is sprayed out of a nozzle at a high pressure, then ignited with a propane torch. In addition, stability tests with respect to high temperature and freeze-thaw cycling are carried out on water-in-oil emulsion type hydraulic fluids. In this type of hydraulic fluid, the fire-resistance is due to the water content: if some water separates out, the remaining fluid becomes less fire-resistant. We are currently carrying out a study on the long-term stability of emulsion type hydraulic fluids, and comparing the separation that occurs in long-term storage with the separation that occurs when the samples are centrifuged.

TABLE 1 - MEAN AND STANDARD DEVIATION OF FLAMEOUT TIMES OF SMALL-SCALE FLAME TESTS

OPERATOR #1					OPERATOR #2		
Set No.	Temp (°C)	R.H. (%)	Product #1	Product #2	Temp (°C)	R.H. (%)	Product #1
1	24	37	11.6 ± 9.0	25.3 ± 8.3	24	18	16.0 ± 11.0
2	25	49	18.5 ± 13.0	23.6 ± 13.1	22	52	18.0 ± 7.0
3	22	41	11.3 ± 10.3	26.2 ± 8.4	26	61	16.0 ± 23.0
4	27	30	4.5 ± 3.7	21.8 ± 4.7	22	51	13.0 ± 7.0
5	21	41	9.5 ± 5.2	29.8 ± 6.4	23	66	23.0 ± 16.0
6	23	59	18.5 ± 8.7	23.3 ± 8.7	19	12	5.6 ± 2.6
7	23	30	23.7 ± 11.4	34.2 ± 7.2	19	15	10.0 ± 5.3
8	22	21	10.0 ± 5.4	26.1 ± 6.8			

TABLE 2 - CRITICAL OXYGEN INDEX TEST RESULTS

OPERATOR #1				OPERATOR #2		
Set No.	Temp (°C)	R.H.	COI (% O_2)	Temp (°C)	R.H.	COI (% O_2)
1	22	37	26.4	24	53	26.4
2	24	56	26.6	22	49	26.3
3	24	42	26.2	26	60	26.3
4	27	32	26.4	22	53	26.3
5	19	45	26.6	24	58	25.9
6	21	62	26.8	22	10	26.0
7	23	29	26.4			
8	21	15	26.6			
Mean			26.5			26.2
Standard Deviation			0.2			0.2

TABLE 3 - HOT-PLATE IGNITION TEST RESULTS (PRODUCT #1)

10-s ignition temperature (°C)			Minimum ignition temperature (°C)	
Set	Operator #1	Operator #2	Operator #1	Operator #2
1	695	680	680	650
2	690	670	680	660
3	690	690	680	660
4	690	675	670	660
5	690	680	670	640
6	690	695	680	680
7	685	---	670	---
Mean	690	682	676	658
Std. Dev.	3	9	5	13

TABLE 4 - COMPARISON OF RESULTS FROM DIFFERENT FLAMMABILITY TESTS

Type of Belt	Propane Gallery	HPI (°C)	OI (% O_2)
PVC	Pass	760-810	29-32
PVC	Fail	680-710	27-28
Rubber	Fail	680-730	27-28
Rubber (non-fire-resistant)	Fail	630-710	23-35

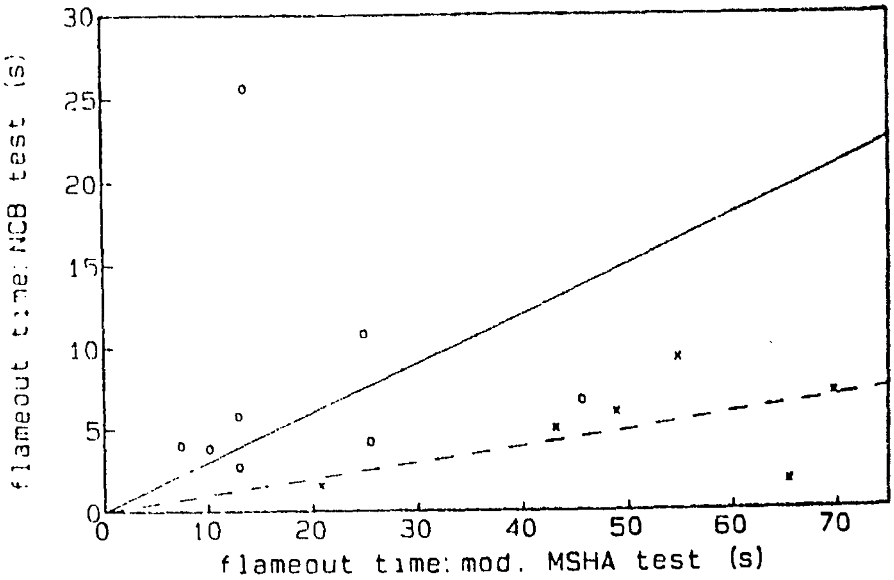

Fig. 1 - The correlation between NCB and modified MSHA flame tests on conveyor belts. The solid line is Type A, the dashed line is Type B.

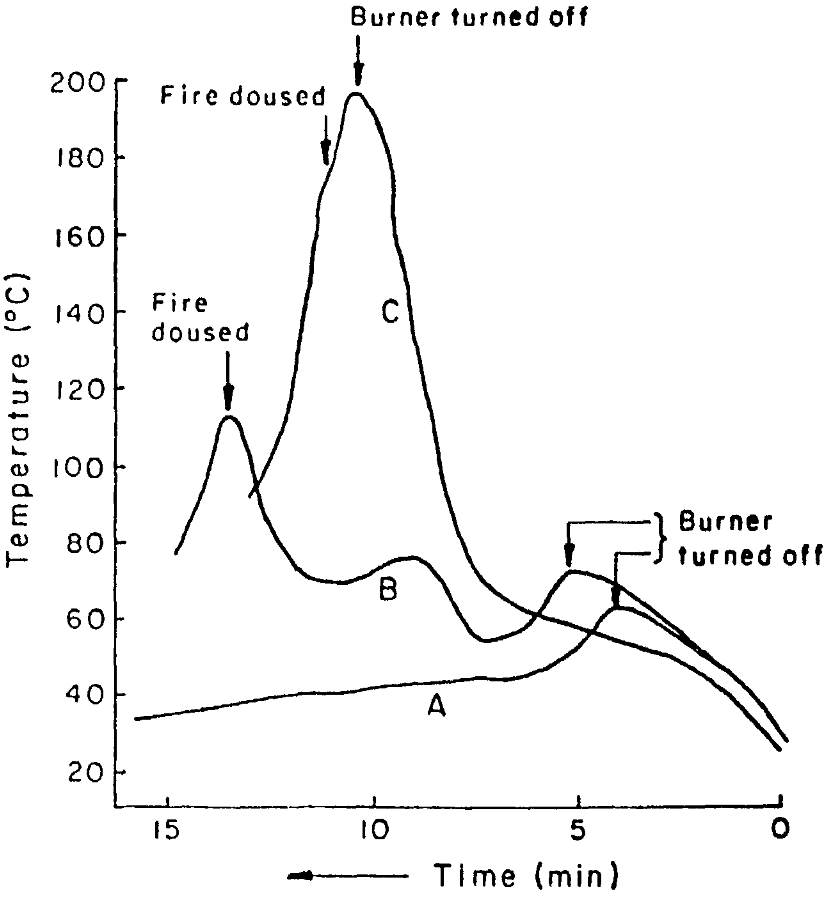

Fig. 2 - Exit temperatures in the propane gallery test on a thin rubber/fabric belt using 3 different burner times.

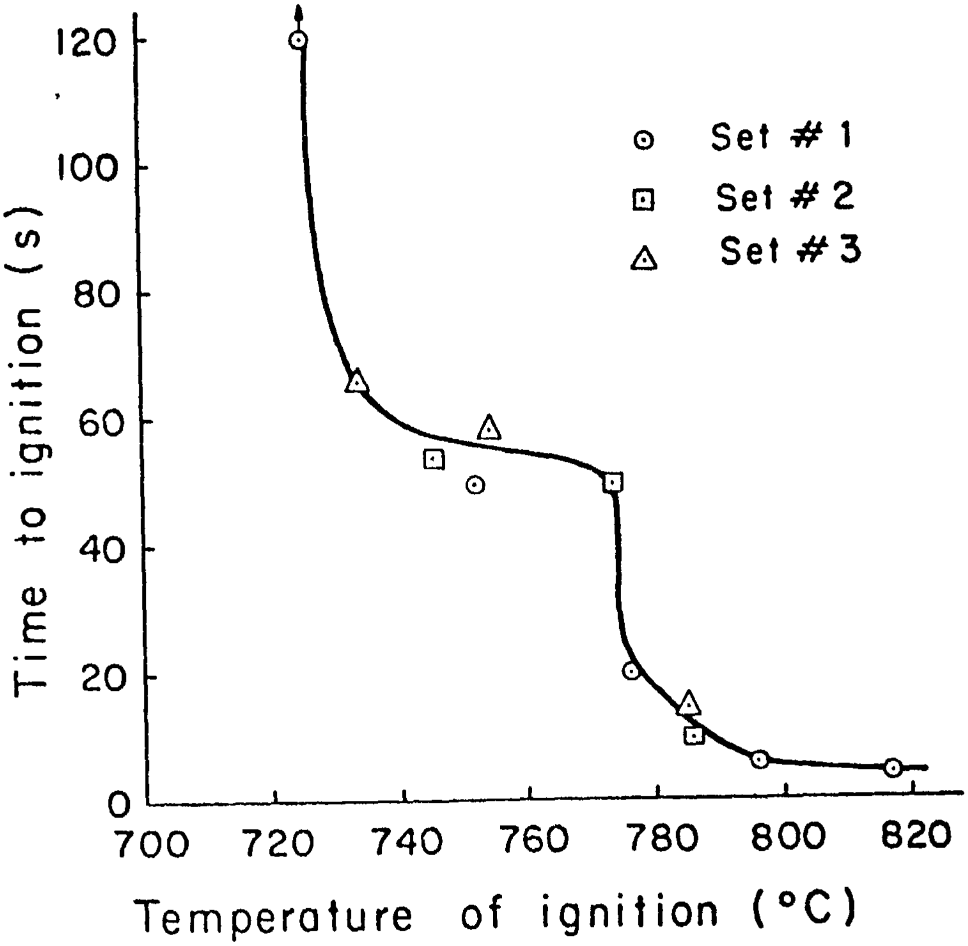

Fig. 3 - Typical results from an HPI test showing the degree of reproducibility that can be expected.

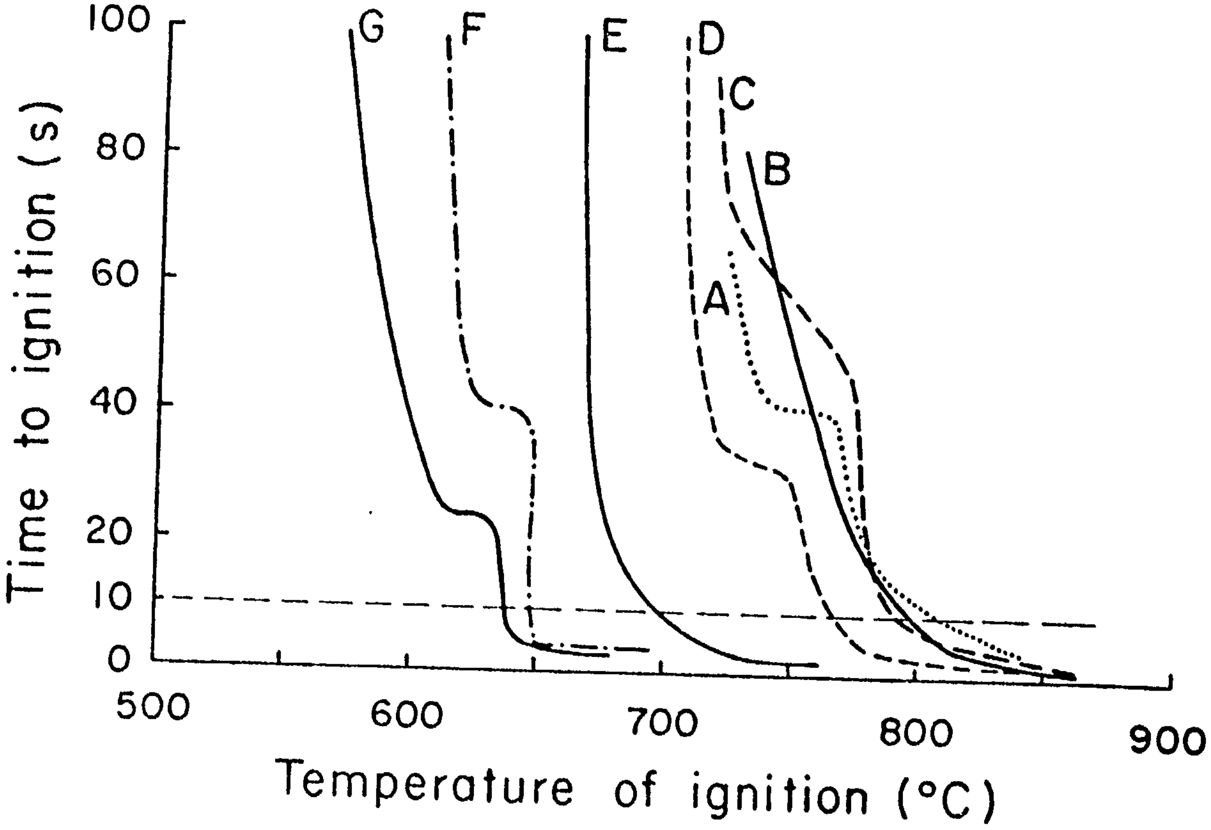

Fig. 4 - HPI results on several different beltings (data points omitted for clarity).

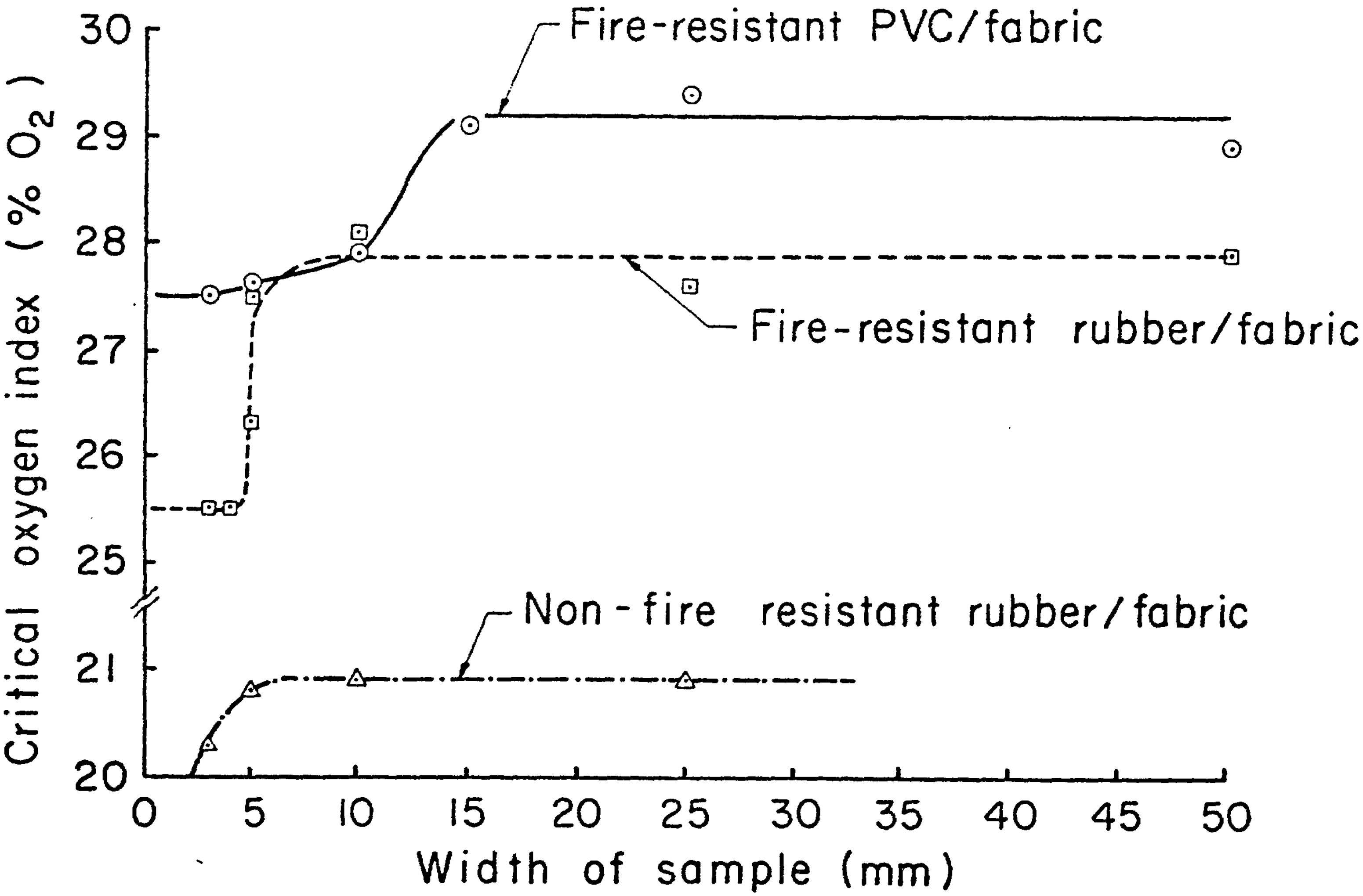

Fig. 5 - Effect of sample width on the critical oxygen index.