International Journal of Mining Science (IJMS)
Volume 10, Issue 1, 2025, PP 27-35
ISSN 2454-9460 (Online)
https://doi.org/10.20431/2454-9460.1001003
www.arcjournals.org

General Requirements, Flammability Testing, Evaluation and Analysis of Brattice Cloths for Mines

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Abstract: *The brattice cloth is used to prevent air leakages from various locations of underground coal mines. Different chemical compositions of material for brattice cloth have been discussed by many researchers. Brattice cloth can become a source of ignition in hazardous areas so it is required to make it non-ignitable. The occurrence of static electricity is highly dependent on the presence of charged chemical species in the cloth. So, it is processed by various chemical processes to nullify the electrical static charge and toxic effect which develop the self-retardant quality of brattice cloth for safe use in underground coal mines. Fire resistance and electrical resistance tests are discussed in the paper as a vital aspect of brattice cloth. The results indicate that the processed brattice cloth can sometimes fail in the specified tests. The present study was carried out to explore the significance of the fire resistance and electrical resistance of brattice cloth in enhancing the safety of hazardous areas.*

Keywords: *Brattice cloth, Fire retardant, Antistatic, Fire resistance test, electrical resistance test*.

1. Introduction

Generally, there is a huge loss of air due to air leakage problems in underground coal mines at or near the bottom of the slope where the highest-pressure differential occurs. Many survey results showed that a little amount of the air handled by the fan reached the last open cross-cuts, the rest of the fresh air has leaked through stoppings, doors, and overcasts directly into return airways, so there is a need to prevent the air leakage by some means.

The brattice cloth is used to prevent air leakages in the mines and, it should be fire retardant (FR) jute-based fabrics either by blending jute with fire retardant fibres and/or by imparting suitable fire-retardant chemical finishes. The flame retardancy and other thermal characteristics of blended or chemically finished fire-retardant jute fabrics are assessed for flammability and antistatic properties as per relevant national and international standards around the globe.

There are several non-durable flame-retardant formulations for cellulosic such as borax, di-ammonium phosphate, borax and boric acid mixture, phosphoric acid etc. Also, the use of such phosphate compounds with melamine-formaldehyde resin has been found to be another alternative method for fire proofing jute goods as semi durable fire-retardant finish of jute, as studied by Bangladesh Jute Research Institute (BJRI). The Tetrakis hydroxyl methyl phosphonium chloride (THPC) based flame retardants can produce toxicological hazards (like formaldehyde toxicity) so it is not eco-friendly during the application and even in end use. So, jute is normally considered ligno-cellulosic fibre to use in floor coverings, upholstery and draperies and even in hazardous areas.

Simple topical applications of FR salts such as ammonium polyphoraphates, coatings or retardant materials is applied topically or through polymerization within the fiber, reacting with functional groups for flame-proofing with high durability and for lowering the thermal decomposition temperature [1].

Some use of brattice cloths is for hurried installation. High places caused by falls of roof are difficult and time-consuming to seal, curtains/barriers, lines of brattice interfere with rock-dusting and clean-up of fine coal etc. In underground mines, brattice cloth stoppings are used to deflect air currents and direct the flow of air to working areas of the underground mine for the most efficient ventilation. The brattice cloth stoppings, sometimes referred to as mine brattices, are curtain-like barriers that are secured to the mine wall or roof and serve as a barrier to close openings such as lateral passageways or the like and to thereby channel the ventilating air circulating throughout the mine along preselected paths.

The brattice cloth material is tested for physical, chemical and performance. In this paper, focus is given on some compulsory tests for flammability and antistatic of brattice cloths used in hazardous areas as per requirements of IS 4355[2]. The flammability testing of materials used in construction, transport and mining provides an authoritative guide to following best practices to ensure safe operation in a hazardous area. The potential fire hazard of certain materials is always a concern where the safety of mining and working personnel is required. The level of fire safety chosen will differ depending on the type of material and the environment in which it is used or applied. It is known that fibre material can produce static energy during use in the hazardous area. The produced energy can become a source of ignition if the produced static energy is more than the ignition energy of the surrounding explosive atmospheres. Materials used for mine stoppings also requires an antistatic test to avoid any source of ignition in the hazardous area. Fire resistance test and electrical resistance test are generally conducted as per different standards, like IS: 11884, IS: 4355 and IS: 4013. The fire resistance test and electrical resistance test on brattice cloth were described for flammability in this paper.

2. Fibres for Brattice Cloths

Natural fibres are composed primarily of cellulose, hemi cellulose, and lignin, with the balance being made up of pectins, water-soluble compounds, waxes, and inorganic, non-flammable substances, which are generally referred to as ash. The decomposition of cellulose between 260°C and 350°C results in the formation of flammable volatiles and gases, non-combustible gases, tars, and some char [3–6]. Hemi cellulose decomposes between 200°C and 260°C but forms more non-combustible gases and less tar than cellulose. Lignin contributes more to char formation than either cellulose or hemicellulose [7, 8]. A high content of cellulose tends to increase the flammability of the fibre.

Manfredi et al. [9] showed the importance of lignin in the thermal decomposition of sisal, flax, and jute fibres, having lignin contents of 9.9, 2.0 and 11.8 %, respectively. They concluded that the lower lignin content in flax contributed to a higher decomposition temperature but resulted in a lower oxidation resistance, which would be provided by the aromatic structure of lignin [10]. Furthermore, there is another important parameter that is the fine structure of the fibre. It also plays a role in the flammability of the fibre [11, 12].

Jute is an affordable natural biodegradable fibre with advantages such as high tensile strength, excellent thermal conductivity, coolness, and ventilation function [13, 14]. Jute falls under a thermoplastic and thermoset matrices of polymer matrix in natural fibre composites. Jute fibre is the best fibre obtained from the bark of a jute plant containing three main categories of chemical compounds, namely cellulose (58–63%), hemi cellulose (20–24%) and lignin (12–15%). The quality of the jute increases if defects are fewer. There are many defects in the jute like rooty, specky, croppy, knotty, dead, runners, hunka, mossy, flabby, heart etc. Natural fibres are not thermoplastic, therefore, when they are subjected to a heat source, pyrolysis and combustion temperatures are encountered before softening or melting temperatures are reached and eventually ignite [15, 16].

Burning of cellulose in the development of better flame retardants is helpful to know what chemical reactions occur when cellulose burns and how the reaction is affected when fabrics are treated with a flame retardant. The burning characteristics of cellulose depend on the chemical and thermal properties of the burning materials [17-18]. Thermal decomposition of cloth material releases numerous combustible gases which can sustain ignition at and above certain concentration levels with oxygen in the air. A burning fabric generating more heat requires less ignition energy to continue its burning [18]. The rapid reaction of degree of polymerization has already been noted, and it has been suggested [19] that the chain breaks occur at strain points at the crystalline-amorphous boundaries. The number of hydroxyl groups decreases while carboxyl groups increase [20]. An effective compound of flame-retardant material forms a glassy skin and stable foam on the fibre surface according to the coating theory. Hence this coating protects the fabric from the air by serving as a barrier to the flame and, it can also trap the air which prevents fire [16, 21]. Generally, jute brattice cloth is used in coal mines. Sharma [22] and Banarjee et al. [23] elaborated that tent-fabric and upholstery fabric for fire safety needs to be finished with a fire-retardant treatment with potassium sodium tartarate (PST) on jute results in a complete self-extinguishing property. Samanta et al. [24, 25] have also described successful semidurable fire-retardant finish of jute fabrics using phosphorous and nitrogenous compounds and studied their thermal degradation behaviour.Many researchers have developed good compounds to make brattice cloth fire retardant [26]. Sometimes the colors of the cloth are also important to measure the whiteness index, yellowness index and brightness index as per th eHunter Lab-Scale formula, ASTM-E-313 [27] formula and ISO-2470-1977 [28] formula respectively, by using a computer-aided Macbeth software and reflectance spectrophotometer. The base fabric shall be jute, cotton or any other fabric of such quantity that satisfies the requirements for fire resistance and electrical resistance properties after treatment.

3. Limiting Oxygen Index

Limiting Oxygen Index (LOI) is critical oxygen index values indicating the relative measure of flammability of any materials or textiles. There is rarely a chance of fire propagation if LOI values are above the certain critical limit. The LOI testing instrument thus provides a precise method for determining the critical oxygen index of the selected untreated and treated fabric sample by measuring the minimum volume concentration of oxygen gas in a flowing stream of mixture of oxygen and nitrogen gases (mixed in different volume ratios) required to maintain candle, like burning of a sample for a specified time as per ASTM-D-2863-77 [29] method and calculated as per following formula.

$$\text{LIO \%} = \frac{100 \text{ x Volume concentration of oxygen}}{\text{Volume concentration of nytrogen} + \text{Volume concentration of oxygen}}$$

4. Ignition Causes for Static Charge in Brattice Cloth

The occurrence of static electricity is highly dependent on the presence of charged chemical species. The charge can be generated in the brattice cloth due to rubbing the cloth or continuous flow of charge of gases in the air. The charge can be minimised by adding the antistatic material during the process of fabrics to make the cloth antistatic type which can be used safely in underground coal mines or any other classified hazardous areas. The static electricity hazards are an electrical phenomenon caused by the generation of large potentials (0.1-100kv) by small charging currents (0.01-100μA) flowing in high resistance circuits (10^8 - $10^{15}\Omega$) [30]. The ignition hazard analysis is carried out to evaluate the resistivity of the brattice cloth to know whether it can produce static electricity. The usefulness of a hazard evaluation is determined largely by the evaluation of flammability to avoid the ignition hazard with respect to any ignition source. It is important to nullify the static charge in the brattice cloth to rule out ignition via static discharges while doing the process of producing the brattice cloth.

The fire-resistant brattice cloth or plastic partition used in an underground coal mine passage to confine the air and force it into the working places. A flame-retarding chemical impregnates in a sufficient amount to impart to make an acceptable flame resistant material. The flammability properties or fire resistance of brattice cloth is required to understand the basic characteristics of material used in underground mines to prevent air leakage and reduce the ignition source and fire hazards.

5. Number of Test and Criteria for Conformity of Flammability of Brattice Cloth

The number of rolls of the same size constitutes a lot. The number of rolls is to be selected for sampling as given below in Table 1 [2] for the assessment and evaluation of brattice cloth.

Table1: *Selection of roll from the lot*

Lot size (N)	No. of rolls (n)
Up to 50	2
51 to 100	3
100 to 200	4
201 to 300	5
301 and above	7

The rolls are selected randomly from the lot in which th erolls are arranged in a systematic manner and starting by numbering from anyone and counting them as 1, 2, 3...., r where r is the integral part of N/n. Sufficient length of brattice cloth should be cut from the selected roll of brattice cloth as a sample for the purposes of tests. More than 25cm of cloth from either end should not be considered for sampling while cutting from the roll. The test specimens are necessary to cut from brattice cloth for the various necessary tests as specified in the relevant standards. The lot may be confirmed to requirements of a particular standard, if the sample has passed all the relevant tests and qualifies the specified limit of the standard.

6. Fire Resistance Test on Brattice Cloth

The combustion process of a polymer can happen in four stages, namely; heating, decomposition or degradation, ignition/inflammation and propagation. When the brattice clothes are in application and come in contact with an energy source, their temperature changes. When the temperature of the polymer layer of brattice cloth exceeds a critical temperature, which will break thermally fragile bonds and degradation will start. The rate of release of volatile products reaches a certain value and mixes with the surrounding environmental air to form a flammable mixture and flame appears. After ignition, combustion will start and polymer is sufficient to allow the evaporation of the fuel. In this condition, the combustion mechanism becomes self-fuelling and flames propagate. Some tests are required to be carried out to resist the flame and to know the time of discontinuation of inflammation and fire-retardant properties. A fire resistance test was carried out to find out the fire-retardant properties of the brattice cloth and details of the tests are described in this paper.

6.1 Fire Resistance Test Set Up

The fuel tank for the burner is clamped on to the side of the test cabinet so that the mean fuel level is approximately 750mm above the base of the burner. The position of the burner is adjusted in such a way that the centre of the burner mouth is 50mm below and 50mm to one side of the nearer lower corner of the test sample. A small asbestos-covered table is fixed to the sample stand about 150mm below the bottom edge of the test sample to avoid any fire in the test set up by falling portion of the burning test sample. A marker wire is stretched horizontally across the stand behind the test sample and is set to 280mm above the bottom edge of the test piece.

Figure.3. *Fire resistance test setup*

Figure 4. *Barthel Burner for fire resistance test.*

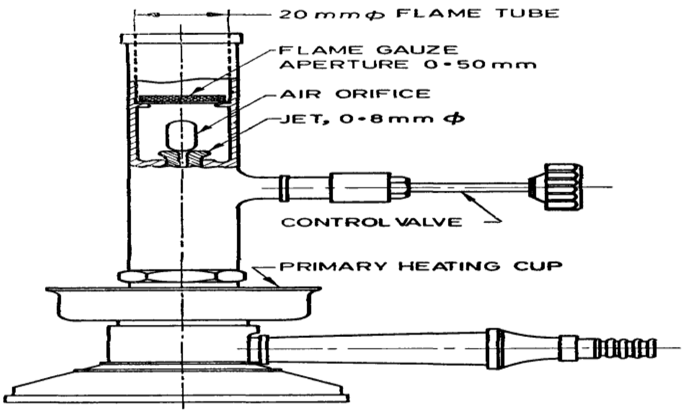

Figure5. *Schematic Diagram of Barthel Burner as per IS 4355*

6.2 Test Sample Preparation For Fire Resistance Test

The test sample preparation procedure as specified by particular standards/guidelines is very important to accomplish the result. For the fire resistance test, the test sample should pass within the specified time when they are placed above the burner flame of the test setup. The precise procedure was followed during the preparation of the test sample for fire resistance and electrical resistance test as specified below:

As per IS 4355, three flammability tests are required on each side of the sample (total six samples) to determine the fire resistance properties of the brattice cloth. Six test pieces were cut in the size of 50mmx550mm each from the test sample for the fire resistance test as shown in Figure 4. Each test sample was turned bent around a fixed 5mm diameter rod as shown in Figure 5. Each sample was pulled from one end to the other. Two movements of a sample were completed in one cycle, then repeated ten times for each sample. After that, each test sample was turned over to the other side and the whole procedure repeated to complete ten cycles. The test sample was maintained in contact with about 180º of the surface of the rod during the whole movement. All loose material was shaken off and cut unwanted edges fibre from the test samples. Then each sample was cut 50mm length from each end and submerged for three hours in about two litres of water at ambient temperature. Then all samples were dried at normal temperature, thereafter suspended freely with both sides exposed for 12 hours. Then the samples were ready to conduct the fire resistance test.

Figure4. *Test sample for fire resistance test*

Figure5. *Cleaning of Test sample thorough movement*

6.3 Fire Resistance Test

A sample of each batch or lot of brattice cloth that contributes to the flame-resistance characteristic shall be inspected or tested to ensure that the finished product will meet the flame-resistance test requirement as per relevant standards. However, the suspended specimen is considered burning only after the burner is removed and the burning time of each specimen was counted. The brattice cloth should meet each of the following criteria:

- Flame propagation of less than 120mm in each of the six tests.
- An average duration of burning should not more than 10seconds in both groups of three tests.
- A duration of burning not exceeding 30seconds in each of the six tests.

Each prepared test piece of 50x450mm was swung above the burner flame and held for 20seconds.

After that, the burner is displaced from the test piece and observed the behaviour closely of each test piece for 30seconds. It was found that the glow on the test piece was completely extinguished within the 30seconds and test results are shown in Table 2. The time was recorded with the help of a calibrated watch. The flame or the glow of the material was not extended above the marker wire during the test. The average persistence time of the flame on the six test pieces was 1.33seconds, which was below the limit of 3 seconds. The persistence time of the flame on any test sample did not cross the limit of 10 seconds. The mean persistence time of the glow on six test pieces was 1.3 seconds, which was below the limit of 10 seconds. The persistence time of the glow on any test sample did not cross the limit of 30 seconds.

The average persistent time of flame/glow was calculated after testing on six specimens, and it was found 1.33seconds, which is within the limit and fulfilled the acceptance performance for brattice cloth.

Table2. *Fire resistance test data*

Sample No.	Duration of application of flame on each sample (second)	Persistent time of flame/glow (second)	Average persistent time of flame/glow (second)	Acceptance value of Average persistent time of flame/glow (second)	Limiting persistent time of flame/glow on any sample (second)
1	20	1	1.33seconds	10 seconds	30seconds
2	20	1			
3	20	2			
4	20	1			
5	20	2			
6	20	1			

7. ELECTRICAL RESISTANCE TEST

The electrical resistance of a fabric is an important design parameter that is influenced by its electrical, mechanical, and chemical properties. The properties of conductive fibers, their inter-connection within a fabric and to external circuitry, and the geometry of the fabric collectively contribute to the electrical resistance of a fabric piece [32]. The value of the electrical resistivity of the material is very important to prevent inflammation and propagation.

7.1 Electrical Resistance Test Set Up

The surface resistance of the brattice cloth is the ratio of DC voltage to the current flowing between two electrodes of the specified configuration that are in contact with the same side of a material as shown in Figure 6.

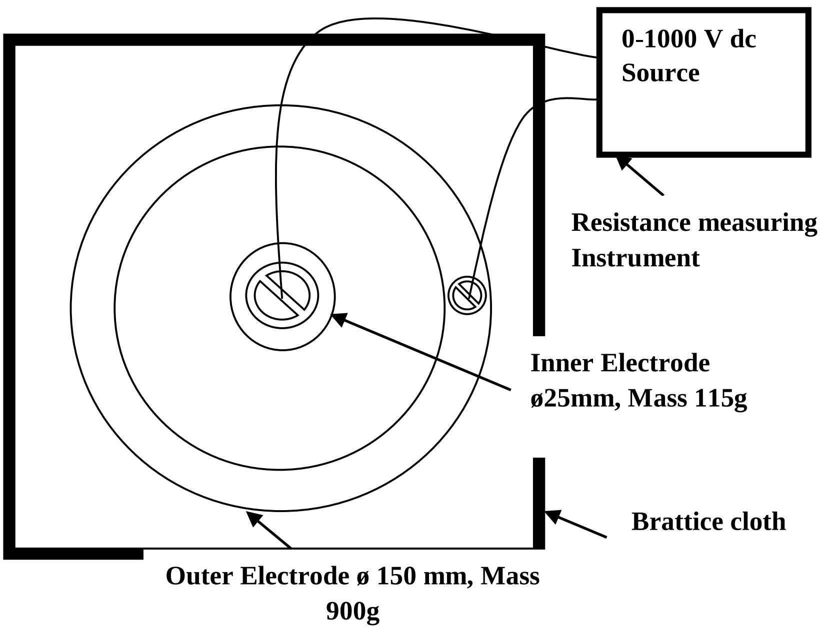

Figure6. *Test set up for electrical resistance test*

7.2 Test sample preparation for electrical resistance test

Two identical test pieces of size 300mm x 300mm were cut from the test sample material. The test pieces were kept at 67% relative humidity and 28ºC temperature for two hours. Both the surfaces of the test pieces were cleaned with Fuller's earth and cotton. After that, all traces of powder were wiped and cleaned with a wet cloth, then cleaned again with a dry clean cloth. One of each surface of the test piece was painted two circles as shown in Figure 6 by using a liquid consisting of 800parts by mass of anhydrous polyethylene glycol of molecular mass 600, 200 parts by mass of water and one part by mass of soft soap to increase the surface electrical conductivity as per requirement of IS 4355 prior to electrical resistance test. The circles marked accurately on the test pieces and painted properly on the marked sample. Excess liquid was wiped with a clean cotton wool pad as a precaution to avoid any wrong measurements.

7.3 Electrical resistance test

For the electrical resistance test, the resistance of the cloth is measured between two electrodes placed on the surface of the brattice cloth and the electrical resistance $10^6\Omega$ value which is below the limiting value of $10^9\Omega$.

A prepared test sample of brattice cloth was placed on the piece of insulating material. The electrodes were put accurately over the painted rings on the test piece. The outer electrode and inner electrode were connected to the earth and the high voltage terminal of the resistance measuring instrument. The electrical resistance was measured by applying 500Vdc for one minute to both the sides of the brattice cloth and measured values are given in Table 3. The measured values comply with the minimum requirement of standards for brattice cloth. The measured average values for Side A and Side B were 19.5 MΩ and 17 MΩ respectively, which are below the limiting value of $10^9\Omega$. The distance of the lead of the electrodes was kept in such a way that they could not touch each other.

Table3. *Electrical resistance test data*

Side A	Side B	Average	Acceptance value as per IS 4355
17 MΩ	22 MΩ	19.5 MΩ	1000 MΩ
15 MΩ	19 MΩ	17.0 MΩ	1000 MΩ

8. Conclusion

Based upon the above results and assessment, it appears reasonable that a laboratory test using a defined procedure for fire resistance and electrical resistance on brattice cloth material, combined with measurements of the fire propagation time and electrical resistance of combustible materials used in underground mines. It can be seen that materials with specified values less than result values would qualify and acceptable materials while materials with respective higher values would entail larger fire risk hazards and consequently be treated as unacceptable material for underground mines application. Those materials do not qualify for the minimum required value for average persistence time and electrical resistivity can produce hazards of toxicity and visibility in the form of the gases and smoke liberated from the materials which can propagate the flame. If the material of brattice cloth is not treated properly with the proper agent and not tested as per the procedure laid down in the relevant standards, it can cause for explosion in the underground mines.

Acknowledgements

The authors gratefully acknowledge the support and facility extended by Director, CSIR-Central Institute of Mining and Fuel Research, Dhanbad to carry out this experimental research study.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Citation: *Dr. Bhagirath Ahirwal (2025). "General Requirements Flammability Testing, Evaluation and Analysis of Brattice Cloths for Mines", International Journal of Mining Science (IJMS), 10(1), pp. 27-35. DOI: https://doi.org/10.20431/2454-9460.1001003.*

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