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Procedia Engineering 45 (2012) 780 – 785

Procedia Engineering

www.elsevier.com/locate/procedia

2012 International Symposium on Safety Science and Technology

# Experimental study of fast sealing airbag in simulating tunnel

JIANG Liming, ZHANG Yinghua, HUANG Zhian*, GAO Yukun, ZHANG Yanfeng

*State Key Laboratory of High-Efficient Mining and Safety of Metal Mines,Beijing University of Science and Technology,Beijing 100083, China*

**Abstract**

Against problems in terms of stability, airtightness and so on of current fast sealing airbag, stability and airtightness of fast sealing airbag in simulating tunnel was studied through combining theoretical analysis and experiment. The ideal viton material is finally found after comparing and analyzing heat resistance, flame resistance, wear resistance, hardness and air permeability of different kinds of rubber. Sealing and wind blocking effects of airbags made from selected material are tested in simulating tunnel. Rate of air leakage and changing rate of wind pressure of each kind of rubber are also determined and further verified, with result that both indexes of viton material are the least, respectively only 4.25% and 4.66%.



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*Keywords*: mine fire;fast sealing device;airbag;airtightness

## 1. Introduction

Mine fire disaster is one of the most serious disasters during the producing process of coal mine, because it poses a very serious threat to underground staffs' safety and health [1]. In order to solve problems such as slow installing speed and bad sealing effect of temporary sealing facilities after mine fire disaster happens, in the early 1990s, technicians of Nanjing Institute of Chinese Coal Researching Institute boldly put forward technical envision of fast sealing airbag according to actual needs and characteristics of relieving and rescuing work in producing site, and successfully completed experiments [2] in tunnel of small section. But result of initial research has some shortcomings, for example, it can only be used in tunnel of small section, its tightness is poor and its transportation is not convenient, which limit its large-scale promotion.

In recent years, with the development of materials technology, studying and improving fast sealing airbag based on original foundation has become a new trend and has great researching value [3]. Through carrying out experimental study of fast sealing airbag in simulating tunnel and analyzing experimental results, the best material to create new type of fast sealing airbag is finally found, and new ideas for developing fast sealing airbag used in mine are finally provided.

## 2. Working principle of new type of fast sealing airbag

The principle of new type of fast sealing airbag is basically as same as principles of traditional ones, as new type of fast sealing airbag and traditional ones all achieve their goals of blocking fresh air into fire zone and preventing toxic and hazardous gases diffusing to non-fire zone through setting up barrier in tunnel to block airflow. The characteristics of working principle of new type of fast sealing airbag is that firstly find proper location in tunnel needed to be sealed to hang corresponding specification of wind blocking cloth, then plenty inflate the cylindrical airbag by using external source of high-pressure air or inert gas so as to make wind blocking cloth fit closely to wall of tunnel, thus achieve the purpose of

* Corresponding author. Tel.: +86-13641010189; fax: +86-10-82385795.
*E-mail address:* huang_za@qq.com

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doi:10.1016/j.proeng.2012.08.239

sealing the tunnel [4]. Under proper condition, two sets of sealing airbags with their spacing being from 1.2 m to 1.5m can be arranged so as to form a pressure balancing space and enhance sealing effect. Temporary sealing facilities can be changed to permanent ones through directly grouting the pressure balancing space when it is needed [5–7]. Specific improvements are as follows.

(1) Improvement of the main material: new type of fast sealing airbag adopts new type of helen rubber as main material, because it has good wear resistance, temperature resistance and elasticity, usually used as surface material of assault boats. This essentially improves performance and sealing effect of new type of airbag.

(2) Improvement of structure: new type of fast sealing airbag optimizes structural design through changing blocking with wall to blocking with airbag and wind blocking cloth, which reduces inflating volume, shortens inflating time and overall improves installing speed of entire fast sealing equipment.

(3) Automatic pressure balance: new type of fast sealing airbag adds automatic pressure balancing device, which fundamentally solves the problem of internal pressure decay in airbag during sealing period, improves reliability of entire equipments and security of staffs because installing staffs can leave safely after entire equipments are installed [8].

The designed structure of new type of fast sealing airbag is shown in Fig 1 (set rectangular cross-section as an example).

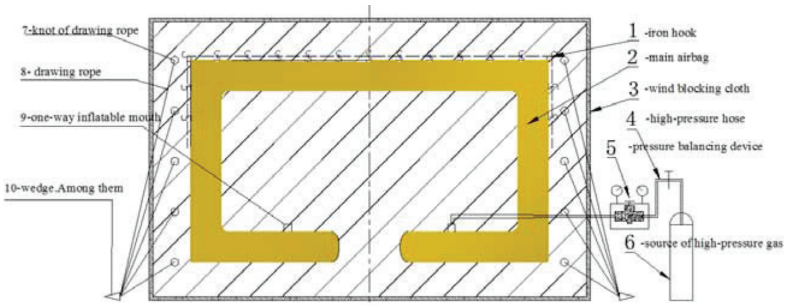


Fig. 1. Designed structure of new type of fast sealing airbag.

As shown in Fig.1, iron hook 1 and knot of drawing rope 7 are bonded evenly and symmetrically on wind blocking cloth 3 with special glue; one-way inflatable mouth 9, pressure balancing device 5 and source of high-pressure gas 6 are linked together by high-pressure hose 4; drawing rope 8 is fixed on wall of tunnel by wedge 10, which can avoid dropping of wind blocking cloth resulting from oversized wind pressure while installing airtight facilities.

## 3. Introduction of rubber selecting method

### *3.1. Selecting method of rubber materials*

Star-shaped contour method [9] is a kind of simple and intuitive method for material selection, through which material is selected on the basis of similar performance.

Firstly select several evaluated items on the basis of selecting requirements and performance indicators of the products, then analyze and evaluate each project, and then score evaluated items by respectively indicating them with 5, 4, 3, 2, 1 which respectively represent excellent, good, fair, poor and inferior degrees.

Evaluate and select material by using star-shaped contour method. The steps are as follows:

(1) Select performance indicating items of product needed to be evaluated, such as strength, flexibility and oil resistance;

(2) Draw two concentric circles, then mark items needed to be evaluated such as strength, flexibility and so forth between inner circle and external circle, and then make each item point to the center of the circle with a ray from the inner circle;

(3) Draw four concentric circles in the inner circle and divide each ray into 4 equal parts, then use intersecting points of five circles and rays to represent scores of each item;

(4) Score each item according to criterion, and mark a point on every sub-ray of corresponding item;

(5) Link all scoring points with a straight line, namely constitute a star-shaped contour.

### *3.2. Rubber selecting criteria*

Rubber selecting criteria is determined on the basis of performance keeping of rubber during underground fire disaster. Its specific performance includes heat resistance, flame resistance, wear resistance, air tightness and some other factors.

(1) Heat resistance.

According to American Society of Automotive Engineers (SAEJ200—1998), heat resistance of all kind of rubber can be divided into nine types (degrees) on the basis of temperature requirement, which is shown in Table 1 (as follows).

Table 1. Rubber material divided by temperature

| Type | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|
| Test temperature/℃ | 70 | 100 | 125 | 150 | 175 | 200 | 225 | 250 | 275 |

Several kinds of commonly used rubber can also be divided into seven degrees according to selected temperature, as shown in Table 2.

(2) Flame resistance.

Oxygen index method is mostly used for evaluating flame resistance of polymers (including rubber). Oxygen index represents the minimum amount of oxygen needed for combustion of mixture of oxygen and nitrogen in sample. Degrees of flame resistance and corresponding ranges of oxygen index of rubber are shown in Table 3.

Table 2. Degree of heat resistance of all kinds of rubber material

| Selected temperature/℃ | Adaptable rubber |
|---|---|
| <70 | Various rubber |
| 70–100 | Natural rubber; SBR |
| 100–130 | CR; NBR; CER |
| 130–150 | BR; EPR; CSM |
| 150–180 | ACM; HNBR |
| 180–200 | ESR; FR |
| 200–250 | DMSR; FR |

Table 3. Degree of flame resistance and corresponding range of oxygen index of rubber

| Degree of flame resistance | Range of oxygen index/% | Examples |
|---|---|---|
| No flame resistance | ≤21 | Combustible rubber not added flame retardants (NR, SBR, etc.) |
| General flame resistance | 21–27 | Combustible rubber added flame retardants |
| High flame resistance | ≥27 | Halogen-containing rubber added flame retardants or not |

The following three standards should be noticed when selecting flame-retardant rubber: the rubber has flame resistance, low occurring rate of combustion and good heat resistance. OI values of commonly used rubber are listed in Table 4.

(3) Wear resistance and hardness.

The airbag should be the wear and tear on rigid surface. So rubber of better hardness should be selected, but if hardness is too large, airbag and wall of tunnel could not fit closely, amount of air leakage would also increase, therefore both factors should be considered while selecting wear-resistant rubber material.

(4) Airtightness.

It is generally believed that rubber that can be used for long time under negative pressure of 10-8-133×10-8 Pa is called vacuum resisting rubber. It has integrated characteristics such as high airtightness, little permeability of air, little weightlessness and so forth. It is also usually divided into four degrees according to the negative-pressure (below atmospheric pressure) requirement of working environment (shown in Table 5).

### *3.3. Performance evaluation of rubber*

After searching and analyzing data, five kinds of rubber are initially selected for evaluation, including styrene-butadiene rubber, butyl rubber, chloroprene rubber, nitrile rubber and fluorine rubber. Through using star-shaped contour method for evaluation, and adopting AutoCAD for automatic calculation, the decreasing order of area of rubber is as follows (Figs.2–6): fluorine rubber, chloroprene rubber, butyl rubber, nitrile rubber and styrene butadiene rubber, so fluorine rubber is ideal material for making airbag.

Table 4. OI of commonly used rubber and plastic

| Name | OI/% | Name | OI/% |
|---|---|---|---|
| EPDM | 17 | CM (Cl 36%) | 27–35 |
| BR | 18–19 | CM (Cl 47.8%) | 42.8 |
| IR | 18–19 | CM (Cl 63%) | 64.0 |
| NR | 20 | CM (Cl 74.5%) | 58.8 |
| SBR | 21–22 | EPM 26 | 41.7 |
| NBR | 21–22 | EPM 23 | 62.0 |
| NBR | 17.5 | PP | 17 |
| NBR26 | 18.0 | PTFE | 95 |
| NBT40 | 19.0 | PVC | 40 |
| CSM | 27–30 | PE | 18 |
| CO | 27–30 | PP | 18 |
| CR | 38–41 | nylon fiber | 20–22 |
| BR | 19–21 | polyester fiber | 20–22 |
| SR | 22–24 | ABS | 18 |
| FPM | >65 | PS | 18 |
| CPR (CM) | 27–30 | PC | 25 |
| BIIR | 18.9 | nylon 6 | 26.5 |
| CIIR | 19.3 | nylon 66 | 30 |
| CSM 20 | 22.5 | PF | 35 |
| CSM 30 | 30.6 | PMMA | 17 |
| CSM 40 | 22.8 | PET | 20 |

Table 5. Degree of vacuum resistance of rubber

| Degree | Pressure/Pa |
|---|---|
| Low vacuum | $133.3\times10^{1}$ |
| Medium vacuum | $133.3\times10^{1}$–$133.3\times10^{-3}$ |
| High vacuum | $133.3\times10^{-3}$–$133.3\times10^{-8}$ |
| Ultrahigh vacuum | $<133.3\times10^{-8}$ |

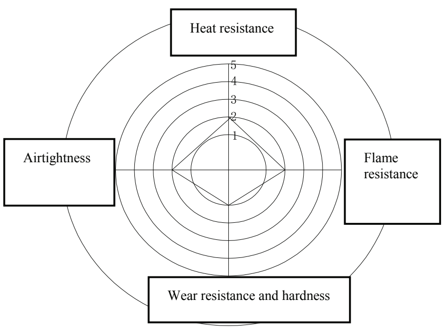


Fig. 2. Styrene-butadiene rubber.

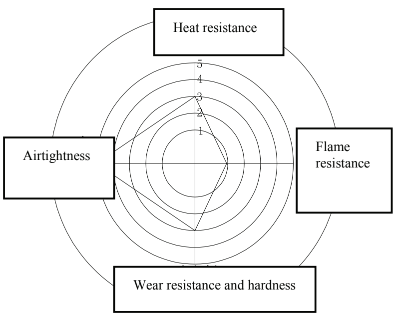


Fig. 3. Butyl rubber.

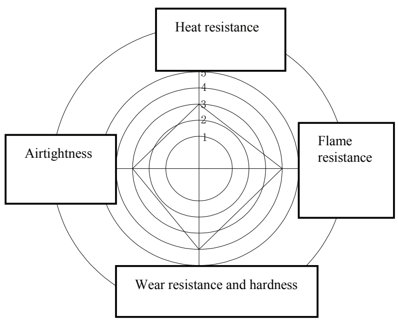


Fig. 4. Chloroprene rubber.

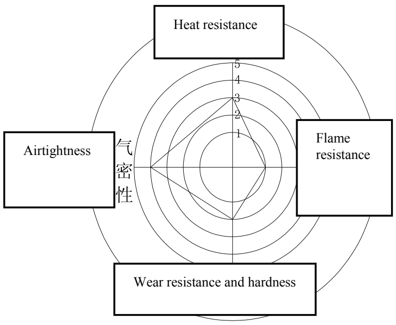


Fig. 5. Nitrile rubber.

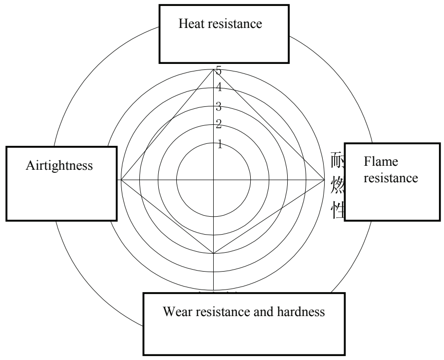


Fig. 6. Fluorine rubber.

## 4. Experimental study of airtightness of new type of fast sealing airbag

### *4.1. Experimental apparatus*

Experimental apparatus include simulating tunnel (square ventilating duct with side length of 28cm) (shown in Fig 7), centrifugal blower (shown in Fig 8), airbags (made from ordinary rubber and fluorine rubber), thermoelectrical anemometer (shown in Fig 9), compensated micromanometer (shown in Fig 10) and so forth.

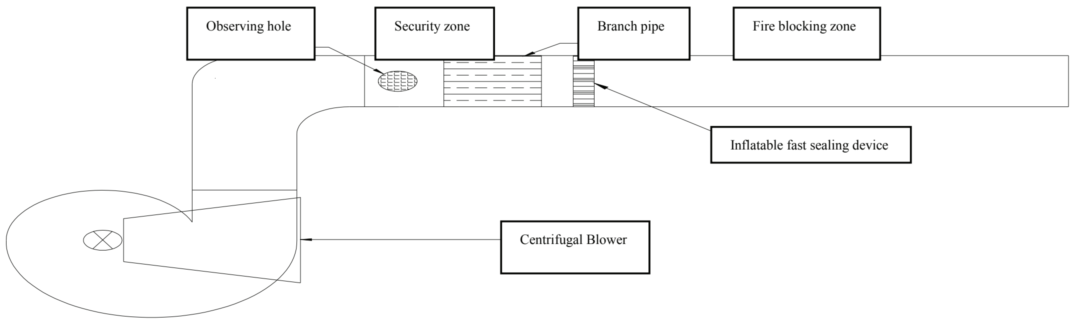


Fig. 7 Schematic diagram of simulating tunnel.

Fig. 8. Centrifugal blower.

Fig. 9. Thermoelectrical anemometer.

Fig. 10. Compensated micromanometer.

### *4.2. Experimental purpose*

Experimental purpose is determining air leaking rates of airbags made from different materials.

### *4.3. Experimental process*

(1) make airbags; (2) link fans and ventilating ducts; (3) install airbags in simulating tunnel (ventilating ducts); (4) select appropriate wind measuring outlets; (5) inflate the airbags; (6) start the fan, and collect data; (7) data analyze and process the data; (8) make conclusion.

### *4.4. Analysis of experimental results*

Table 6 shows that the air leaking rate and corresponding pressure changing rate of fluorine rubber airbag are respectively 4.25% and 4.66%, which are the least. The good sealing effect of fluorine rubber airbag further validates results of theoretical analysis and makes expected goal achieved.

Table 6. Air leakage of airbag

| Items | Ordinary rubber airbag | SBR airbag | BR airbag | CR airbag | NBR airbag | FR airbag |
|---|---|---|---|---|---|---|
| Wind velocity before sealing V1/(m·s-1) | 2.35 | 2.35 | 2.35 | 2.35 | 2.35 | 2.35 |
| Wind velocity after sealing V2/(m·s-1) | 0.20 | 0.21 | 0.17 | 0.15 | 0.18 | 0.10 |
| Forward pressure of sealing device P1/Pa | 107 591 | 107 591 | 107 591 | 107 591 | 107 591 | 107 591 |
| Back pressure of sealing device P2/Pa | 107 000 | 107 000 | 106 880 | 107 050 | 106 950 | 107 089 |
| Difference of forward and back pressure of sealing device P3/Pa | 591 | 591 | 711 | 541 | 641 | 502 |
| Rate of air leakage L1/% | 8.50 | 8.94 | 7.23 | 6.38 | 7.66 | 4.25 |
| Relative change of pressure ΔP/% | 5.49% | 5.49% | 6.61% | 5.01% | 5.95% | 4.66% |

## 5. Conclusions

(1) PTFE rubber is selected as the preferred material of airbag for inflatable fast sealing device. According to star-shaped contour method, heat resistance, flame resistance, air tightness and wear resistance of PTFE rubber respectively scored 5 points, 5 points, 4 points and 3 points. Viton has strong heat resistance, excellent flame resistance and air tightness, except that its wear resistance is slightly insufficient. So viton is selected as the material for research of air tightness and variation of the security zone.

(2) The new type of fast sealing airbag takes airbag as framework and blocks wind with cloth, mainly being composed of main airbag, wind blocking cloth, pressure balancing device and other accessories. The order of installation is that firstly hanging wind blocking cloth and airbag at appropriate location, then debugging inflatable device and testing its airtightness, finally deflating and sorting out after sealing process is over.

(3) The underground sealing experiment aiming at fast sealing airbag determines speeds of air leaking of fluorine rubber, chloroprene rubber, butyl rubber, nitrile rubber and styrene-butadiene rubber with thermoelectric type anemometer. Results of the experiment are respectively 4.25%, 6.38%, 7.23%, 7.66% and 8.94%, which verify good sealing effect of airbag made from fluorine rubber and makes expected goals achieved.

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