# THERMOSTABLE TEXTILE MATERIALS USED IN EMERGENCY EVACUATION SYSTEMS OF PASSENGER AIRPLANES

***K.M. Kirin, **G.A. Budnitskiy, ***V.A. Nikishin**

* Aviation Certification Center of State Scientific-Research Institute of Civil Aviation,
** "LIRSOT" - All-Russian Scientific-Research Institute of Polymeric Fibers,
*** Russian Correspondence Institute of Textile and Light Industry

## ABSTRACT

Quick evacuation of passengers and containment of fire growth in an airplane cabin play an important role in ensuring passengers' survivability in case of a fire aboard an airplane. The use of thermostable (heat-resistant) materials is capable of solving this problem, however, high cost of such materials limits their wide employment.

One of the fields for the heat-resistant materials application is the inflatable of the emergency evacuation slide, which has large internal volume and is inflated by pyrotechnic inflation system.

Below are shown the results of tests, aimed at determining heat release rates of existing Russian- and foreign-manufactured materials of emergency evacuation slides. Also there are show the results of tests new materials, based on para-aramid (Armos®), polyimide (Arimid®), and newly developed para-metaaramid (Tverlana®) fibers, created by experts from the All-Russian Scientific-Research Institute of Polymeric Fibers, and which are coated with airtight coatings similar to the ones used in Russian emergency evacuation slides.

The use of Arimid® heat-resistant textile material, featuring a high heat-resistance combined with a fluorine rubber coating, allows better test results with a lower heat release to be achieved.

On our opinion, the new Tverlana® para-metaaramid fiber is the most suitable material for manufacturing inflatable tubes of emergency evacuation slides, since it has the best combination of cost-efficiency and physical propertys.

## INTRODUCTION

An inflatable evacuation slide, which enables passengers to quickly egress from an airplane in case of fire, without waiting for rescue teams, is the main component of an emergency evacuation system.

When developing an evacuation slide of large internal volume, designers face a problem of creating an efficient inflation system. Employment of the widely used aspirator-type inflation system results in a considerable increase in the weight of compressed gas bottle(s). Pyrotechnic inflation systems (nitrogen generators) will increase the weight efficiency of the inflation system. However, quite a high temperature (130-400°C) of the gas, supplied into the evacuation slide inflatable tube, may lead to damaging this tube.

The existing Russian-produced heat-resistant textile materials possess the necessary resistance to high temperatures, however, because of their high cost, production rates of such materials remain very low, while they are being mainly used in the crucial components of aerospace and missile systems [1, 2].

The new Tverlana® para-metaaramid fiber, created in 1999 by specialists from the All-Russian Scientific-Research Institute of Polymeric Fibers, [Russian patent 2180369, 2002] (Fig. 1), combines a favorable cost-efficiency of metaaramid fibers and a high fire-resistance [3].

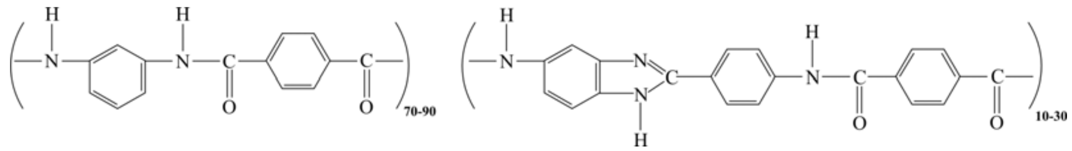

Fig. 1 Structural formula of Tverlana® fiber.

Table 1 and Figure 2 show physical propertys of heat-resistant fibers, produced in Russia, as compared with the polyester fiber, which dominates on the world chemical fiber market and which production totals 60% of the market [4].

Table 1

**Physical properties of Russian heat-resistant fibers [2, 3]**

| Characteristics | SVM | Armos | Arimid-S | Tverlana | Polyester |
|---|---|---|---|---|---|
| Density, gram/cm$^3$ | 1.44 | 1.44 | 1.43 | 1.38 | 1.38 |
| Tensile Strength, cH/tex | 160-235 | 250-290 | 50 | 30-60 | 80 |
| Tensile Modulus, GPa | 125-140 | 145-160 | 15-25 | 14 | 15 |
| Elongation at Break, % | 4.2-4.5 | 4.5-5.5 | up to 18 | 12-17 | 25 |
| Equilibrium Humidity, % | 4-7 | 3.5-5.0 | 5-6 | 11-12 | 0.4 |
| Thermal resistance, % at 250°C, 325 hours<br>at 300°C, 100 hours | 60-65<br>20-30 | 60-65<br>25-30 | --<br>70-80 | --<br>-- | |
| Temperature, °C - glass-transition<br>- decomposition | 270-280<br>450-520 | 270-280<br>450-520 | 380-450<br>520-550 | --<br>400 | 74 |
| Limiting Oxygen Index, % | 38-42 | 38-42 | up to 50 | 35-37 | 17 |

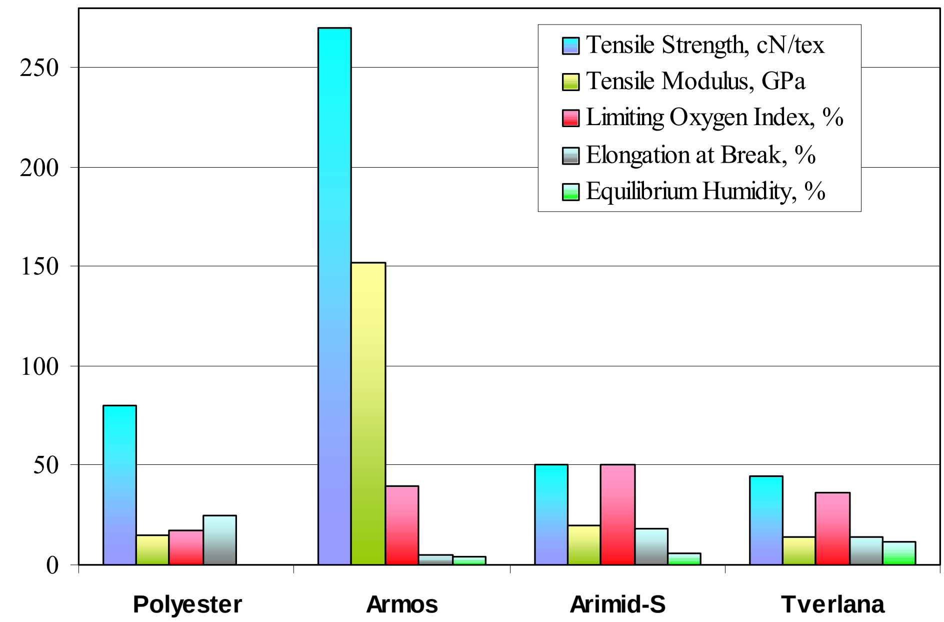


Fig. 2 Correlation of physical and thermal propertys of materials, produced in Russia.

Comparison tests have been conducted in order to compare heat release rates of existing Russian- and foreign-produced materials used for emergency evacuation slides, as well as specially prepared experimental samples, made of heat-resistant paraaramid (Armos®), para-metaaramid (Tverlana®), and polyimide (Arimid®) fabrics, coated by non-stereoregular butadiene rubber (SKB).

## METHODS

The tests have been conducted in compliance with the standard methods given in FAR-25, Appendix F, Part IV "Test Method to Determine the Heat Release Rate from Cabin Materials Exposed to Radiant Heat", on the Rate of Heat Release Apparatus at the laboratory of the VIAM State Scientific Center:

Atlas Heat Release Rate System P/N: HRR 3,
Serial number HRR-1011,
FAA Project SP822CH-Q-2, data 8/12/96.

During the tests, the samples were subjected to a heat current of 3.5 $W/cm^2$. Moreover, the tests were also aimed at determining the flammability of material samples in accordence of determining the limiting oxygen index (LOI).

## MATERIALS

The following material samples of Russian- and foreign-produced inflatable tubes of the emergency evacuation slides have been submitted by enterprises, mass-producing emergency evacuation slides for the aircraft industry:

- ✓ M-11849 (used in Il-96M evacuation system) and M-12040 (Be-200) provided by Air Cruisers Company (USA),
- ✓ 8-170 (Tu-204) provided by Ufa Factory of Elastomeric Materials and Structures (UZEMIK),
- ✓ 8-238 (Il-86) provided by Zvezda Scientific Industrial Enterprise,
- ✓ 30 (Tu-154) provided by YaroslavRezinoTekhnika Joint-Stock Company.

In addition, the tests also involved the use of specially manufactured samples of experimental textile materials, based on paraaramid (Armos®), meta-aramid (Tverlana®), and polyimide (Arimid®) fibers. The non-stereoregular sodium-butadiene rubber (SKB), mixed with aluminum powder, whose structure and composition are totally identical to those of Russian-production coating (8-170) of slide tube, was used as the samples coating.

The tests also involved the use of the off-the-shelf polyimide fabric 51-ZT-166, coated with the SKF-26 fluorine rubber, which had been submitted by “LIRSOT” company.

## RESULTS AND DISCUSSIONS

Table 2 and Figure 3 give summarized results of testing of coated materials used in the inflatable tubes of emergency evacuation slides.

Table 2

**Test results of coated materials of slide tubes.**

| Material (marking of goods) | Surface density, gram/m$^2$ | Max heat release rate, kW/m$^2$ | Time to maximum heat release rate, sec. | Total heat release during 2 min, kW·min/m$^2$ | Limiting Oxygen Index (LOI), % |
|---|---|---|---|---|---|
| 30, (TN-2 slide for Tu-154) | 555-600 | 328.59 | 29.5 | 213.47 | 19 |
| 8-238, (TND slide for IL-86) | 440 | 185.75 | 36.0 | 142.77 | 17 |
| 8-170, (TNO-3 slide for Tu-214) | 280 | 325.86 | 15 | 103.75 | 18 |
| M-11849, (63681 slide for IL-96) | 262 | 55.92 | 12.5 | 49.39 | 22 |
| M-12040, (65600 slide for Be-200) | 275 | 69.99 | 18.0 | 38.58 | 22 |

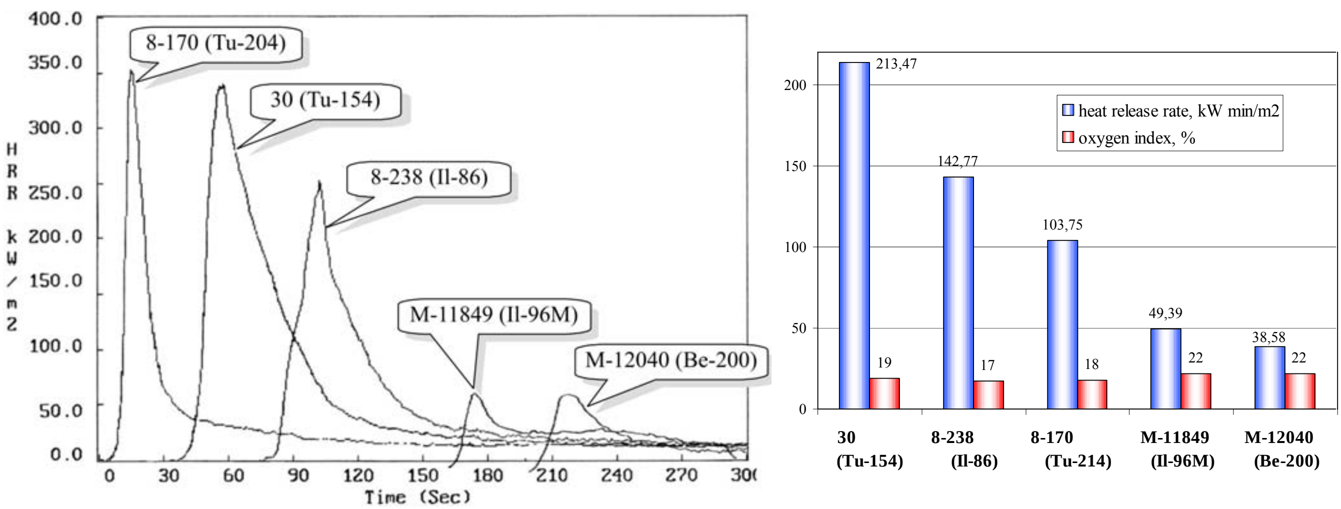


Fig. 3 Heat release rate and limiting oxygen index of materials of the slide tubes (horizontally shifted for clarity).

Foreign textile materials M-11849 and M-12040 use polyamide Nylon-6.6 ($T_{melting}$=280°C) as a base, while they are coated with polyurethane, based on polyester mixed with aluminum powder. These textile materials demonstrated the lowest value of total heat release rate.

Fabric (30 and 8-238) of earlier-produced Russian slide inflatables had the basis in form of polyamide Nylon-6 (caprone) ($T_{melting}$=230°C), coated with polyisobutylene and ethylene-propylene rubber, and demonstrated the highest value of total heat release rate among the samples tested.

The more modern material 8-170 uses polyester fabric ($T_{melting}$=265°C) as the base, which is covered with aluminum-backed coating based on non-stereoregular sodium-butadiene rubber (SKB). Its total heat release rate is slightly lower than that of the textile materials, used in the earlier inflatables, however, the intensity of the heat release at the first moment is quite considerable.

Table 3 and Figure 4 demonstrate test results of specially manufactured experimental samples of heat-resistant textile materials Armos®, Tverlana®, and Arimid®, coated with the non-stereoregular sodium-butadiene rubber (SKB), identical to the coating of Russian-produced slides. They also show test results of Arimid® fabric 51-ZT-166, coated with the SKF-26 fluorine rubber coating.

Table 3

**Test results of coated heat-resistant textile materials**

| Material (marking of goods) | Surface density, gram/m$^2$ | Max heat release rate, kW/m$^2$ | Time to maximum heat release rate, sec. | Total heat release during 2 min, kW·min/m$^2$ | Limiting Oxygen Index (LOI), % |
|---|---|---|---|---|---|
| 51-ZT-166 | 214 | 40.88 | 11.0 | 18.19 | 49 |
| Armos+SKB | 344 | 144.15 | 17.3 | 74.0 | 21 |
| Arimid+SKB | 335 | 209.59 | 15.3 | 86.66 | 19 |
| Tverlana+SKB | 450 | 286.05 | 23.0 | 115.88 | 19 |

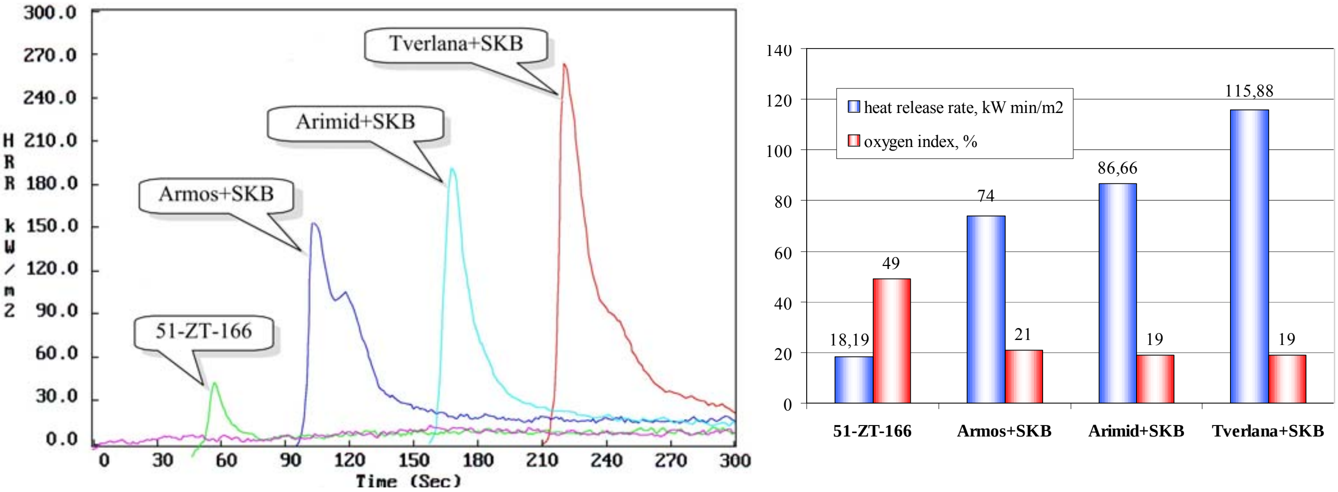


Fig. 4 Heat release rate and oxygen index of coated heat-resistant textile materials (horizontally shifted for clarity).

In order to take into account the influence of the fabric base and coating weight on the test results, the total heat release rate is reduced to the heat release rate of a gram of the sample.

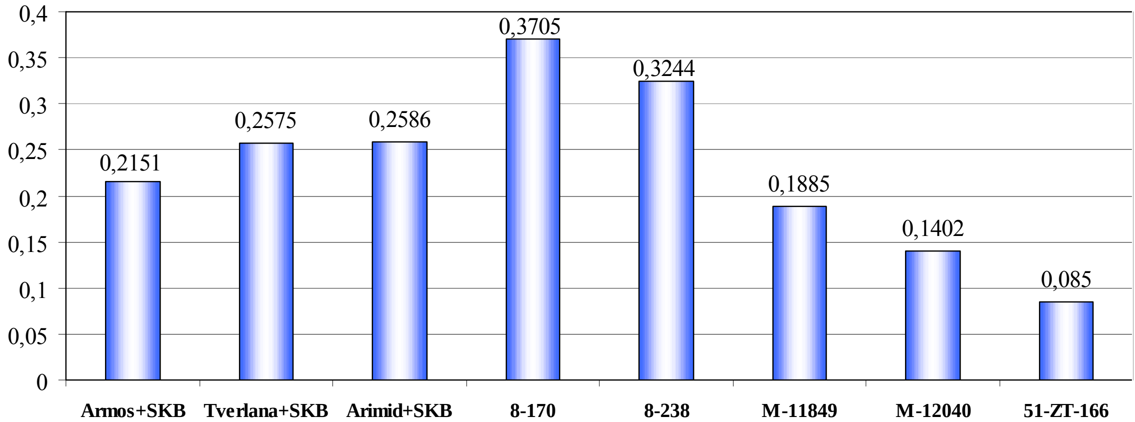


Fig. 5 Specific total heat release rate (kW·min/gram)

When comparing the specific heat release rates (Fig. 5), it is clear that characteristics of experimental samples, made of heat-resistant fibers, have shown the best results with a lower heat release rate as compared with samples made of polyester fibers. However, it is obviously not sufficient for reaching the heat release rate of foreign samples.

The use of more heat-resistant fluorine rubber coating (SKF-26), applied over the polyimide textile material (51-ZT-166), allows the test results of both experimental and foreign samples to be surpassed.

Since the heat release rate depends on both the base material and the coating, it is of interest to determine the share of each component in the total heat release rate. Table 4 shows test results of textile materials without coatings.

Table 4

**Test results of heat-resistant textile materials without coatings.**

| Material | Surface density, gram/m$^2$ | Max heat release rate, kW/m$^2$ | Time to maximum heat release rate, sec. | Total heat release during 2 min, kW·min/m$^2$ | Limiting Oxygen Index (LOI), % |
|---|---|---|---|---|---|
| Armos | 197 | 39.18 | 24.7 | 22.4 | 36 |
| Arimid | 145 | 11.34 | 194.7 | 4.19 | 60 |
| Tverlana | 202 | 45.18 | 17.7 | 24.8 | 31 |

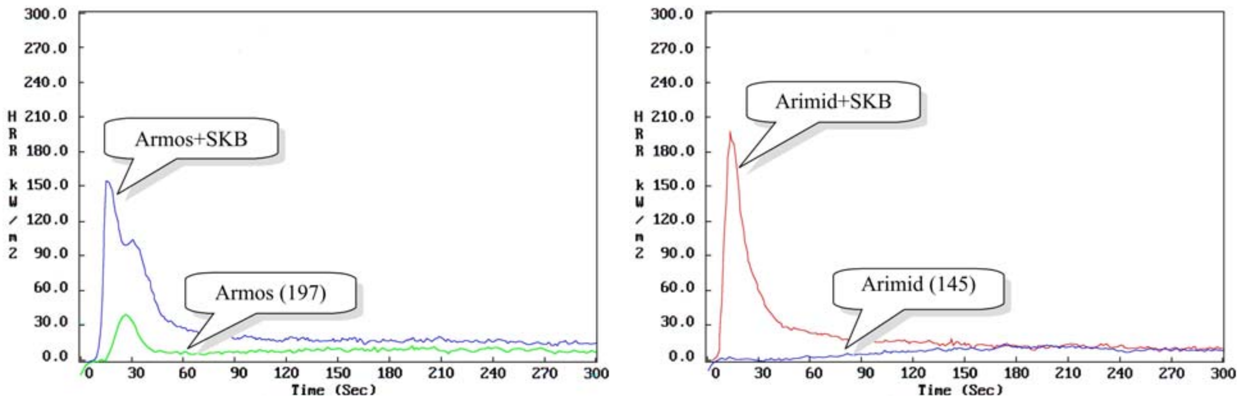

Fig. 6 Changes in Armos and Arimid heat release rates after coating.

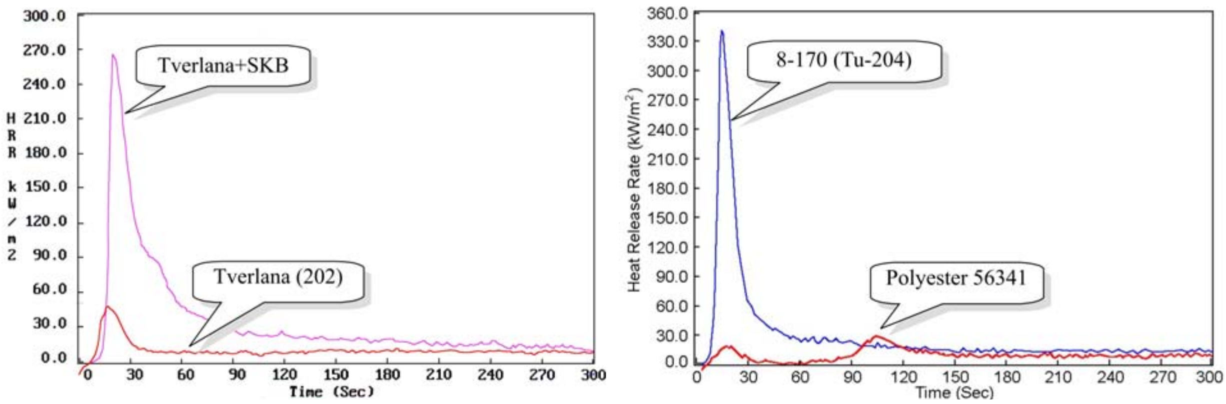

Fig. 7 Changes in Tverlana heat release rate after coating.

Table 5, Figures 6, 7 and 8 demonstrate changes in the heat release rate after the materials have been coated.

Table 5

**Coating influence on heat releas rate.**

| Material | Fabric without coating | | | Coated fabric | | | SKB coating | |
|---|---|---|---|---|---|---|---|---|
| | Surface density, gram/m$^2$ | Oxygen Index (LOI), % | Total heat release, kW·min/m$^2$ | Surface density, gram/m$^2$ | Oxygen Index (LOI), % | Total heat release, kW·min/m$^2$ | Δ surface density, gram/m$^2$ | Δ total heat release, kW·min/m$^2$ |
| Armos | 197 | 36 | 22.4 | 344 | 21 | 74 | 147 | 51.6 |
| Arimid | 145 | 60 | 4.2 | 335 | 19 | 86.7 | 190 | 82.5 |
| Tverlana | 202 | 31 | 24.8 | 450 | 19 | 115.9 | 248 | 91 |

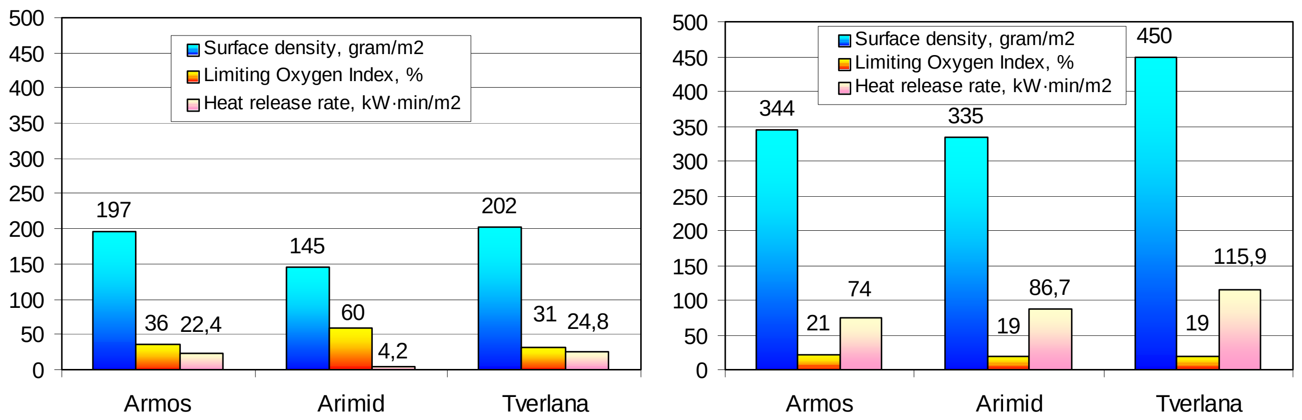


Fig. 8 Before anf after coating application

As it is follows from the received data, different increases in heat release rates of samples, covered with the same coating, are caused by different weight of the coating. In its turn, it depends on the structure of the textile material and its absorbing capability. For instance, weight of the non-stereoregular sodium-butadiene rubber coating on Tverlana (staple fabric) was 248 gram/m$^2$, on Arimid - 190 gram/m$^2$, and on Armos - 147 gram/m$^2$.

## SUMMARY

Application of one of the heat-resistant textile materials - Armos®, Arimid®, or Tverlana® - as the base for inflatable tube of emergency evacuation slide, and the earlier-used SKB sodium-butadiene coating, allows the heat release characteristics to be improved only slightly as compared with those of similar Russian materials (8-170). In order to reach the heat release rate of foreign textile materials (M-11849), it is necessary to employ a more heat-resistant coating. This statement is proved by test results of the Arimid® textile material, coated with the fluorine rubber coating (51-ZT-166), which features the best heat release rate among all samples tested (Fig. 9).

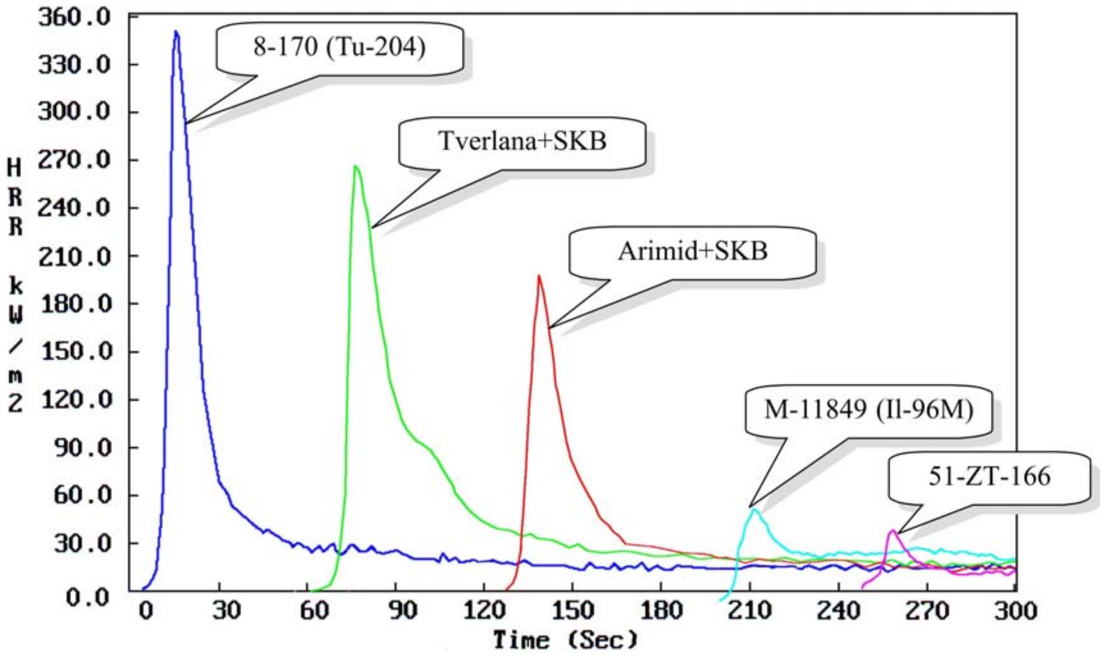


Fig. 9 Comparison of heat release rates of existing and experimental coated samples.
(horizontally shifted for clarity).

In order to select one or another textile material as the base for tube of emergency evacuation slide, it is essential to take into account the cost of such textile material. In spite of its lower thermal characteristics, the use of Tverlana® material as the base material for inflatable tube of emergency evacuation slide is more economically expedient.

## CONCLUSIONS

1. Application of Armos®, Arimid®, and Tverlana® heat-resistant textile materials as the base for inflatable tube of emergency evacuation slide, and the earlier-used SKB sodium-butadiene rubber coating allows the heat release characteristics to be slightly improved as compared with those of existing polyester samples. However, it is obviously not sufficient for reaching the heat release rate of foreign analogues.

2. The SKB coating has a considerable influence on the heat release rate and does not allow the material to realize all the advantages of heat-resistant textile materials of the fabric base.

3. The use of the Arimid® polyimide heat-resistant textile material in combination with the SKF-26 fluorine rubber coating, which features a high heat resistance allows the better results with a lower heat release rate to be achieved, as compared with those of foreign analogues.

4. On our opinion, the Tverlana para-metaaramid fiber is the most suitable material for manufacturing the airtight material for inflatable tube of emergency evacuation slides, since it has the most optimal combination of cost-efficiency and thermo-mechanical propertys.

**ACKNOWLEDGEMENTS**

The authors would like to thank Gorbacheva N.M., Permenova L.I., Zabbarova R.S. - employees of the technical department of the Ufa Factory of Elastomeric Materials, Products, and Designs (Bashkortostan Republic), for their work on applying the coating on the samples. We would also like to express their gratitude to Vorobiev V.N. and Barbotko S.L. - employees of the laboratories of VIAM State Scientific Center, for conducting experiments on determining the heat release rates, as well as to Drozd L.I., LIRSOT employee, for carrying out tests on determining physical propertys of the samples.

Special gratitude for support and assistance in getting samples and technical documentation is expressed to Jose Redento, President of Air Cruisers Company (USA), as well as to Shubnyakov D.E. and Shemanaev M.Yu., employees of Russian representative of Air Cruisers Company, as well as to Kostev Yu.A., consultant of Aviation Register of the Interstate Aviation Committee.

**REFERENCES**

1. Development of high-strength, heat- and fire-proof synthetic fibers, Volokhina A.V., Shchetinin A.M., All-Russian Research Institute for Polymer Fibers, Mytishchi, Chemical Fibers, 2001, No. 2, pg. 14-21.

2. Third-generation chemical fibers, produced in the USSR, Avrorova L.V., Volokhina A.V., Glazunov V.B., Kudryavtsev G.I., Makarova R.A., Oprits Z.G., Tokarev A.V., Semenova A.S., All-Russian Research Institute for Polymer Fibers, Mytishchi, Chemical Fibers, No. 4, 1989, pg. 21-26.

3. Thermal-resistant polyamide benzimidazolene fiber Tverlane, Machalaba N.N., Budnitskii G.A., Volokhina A.V., Lukasheva N.V., Kiya-Oglu V.N., Ogneva T.M., Pedchenko N.V., Poleeva I.V., Sokira A.N., All-Russian Research Institute for Polymer Fibers, Mytishchi, Chemical Fibers, No. 4, 2002, pg. 52-54.

4. World production of textile raw materials in 2002, Aizenshtein E.M., Chemical Fibers, No. 1, 2004, pg. 3-7.