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Thermal insulating cover for the metal body of a rocket motor
Osłona termoizolacyjna metalowego korpusu silnika rakietowego

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Abstract: *Many years of experience in the design and manufacturing technology of ammunition and rockets by BUMAR AMUNICJA S.A. enabled undertaking, together with the Institute IMPiB Department Elastomers and Rubber Technology in Piastów, the task of developing an upgraded insulation cover for the metal body of the rocket motor of the GROM-M system.*
The insulating layer of the metal body of the motor is characterised by the fact that local thermal exposure occurring during rocket propellant combustion, often causes the motor body to burn through locally. Applying an insulating composition matched to the temperature of combustion of the rocket motor, brings about a carbonisation process applicable to this temperature. Thus, it provides a sufficient layer of carbon-carbon phase composite at the site to enhance the strength of the motor and protect the above-mentioned metal body from exposure to heat during combustion of the rocket propellant.
The thermal insulating layer is a double layered coating consisting of a layer of rubber compound and a layer of impregnated carbon cloth. To obtain uniformity of the insulating layer and hence its heat resistance, similar components are used in the composition of the rubber compound for impregnating a composite based on carbon cloth: the same type of rubber, the same phenol-formaldehyde resin and the same vulcanising agents.
Streszczenie: *Wieloletnie doświadczenie firmy BUMAR AMUNICJA S.A. w zakresie konstrukcji i technologii produkcji amunicji i rakiet, pozwoliło na podjęcie się zadania, wspólnie z Instytutem IMPiB Oddziału Elastomerów i Technologii Gumy w Piastowie, stworzenia zmodernizowanej osłony termoizolacyjnej do metalowego korpusu silnika rakietowego do wyrobu GROM-M.*
Warstwa izolacyjna metalowego korpusu silnika rakietowego charakteryzuje się tym, że miejscowe narażenia termiczne występujące w czasie spalania paliwa rakietowego, często wywołują miejscowe przepalenia korpusu silnika. W przypadku zastosowanego składu warstwy izolacyjnej zależnie od temperatury spalania w danym miejscu silnika wywołują odpowiedni dla tej temperatury przebieg procesu karbonizacji. Zapewniając tym samym wystarczającą w tym miejscu warstwę kompozytu fazy

węgiel-węgiel zwiększającą wytrzymałość silnika oraz zabezpieczającą wspomniany metalowy korpus przed narażeniem termicznym w czasie spalania paliwa rakietowego.
Warstwa termoizolacyjna silnika rakietowego jest powłoką dwuwarstwową składającą się z warstwy mieszanki kauczukowej i warstwy impregnowanej tkaniny węglowej. Dla uzyskania jednolitej struktury warstwy izolacji i jej odporności termicznej, w składzie mieszanki kauczukowej i w mieszance kauczukowej do impregnacji kompozytu na bazie tkaniny węglowej stosowane są podobne składniki: ten sam typ kauczuku, ta sama żywica fenolowo-formaldehydowa oraz te same substancje wulkanizacyjne.

Keywords: *thermal insulation, rocket motor*
Słowa kluczowe: *termoizolacja, silnik rakietowy*

1. Introduction

During its operation, a rocket motor is subjected to a very complex pattern of thermal loads and mechanical strains caused by high pressures of combustion as well as strains caused during the rocket's flight by inertial loads resulting from changes in speed and direction of flight.
At the same time, combustion products with temperatures exceeding the melting point of the construction materials, flowing along the walls of the combustion chamber, heat them intensively from the inside, creating a temperature field in the wall material which is not determined in time and is spatially variable.
A typical rocket motor body is made of an alloy steel with high durability and resistance to temperature. Such a body, however, does not withstand the thermal exposure occurring during the combustion of rocket fuel. For this reason, the motor body is additionally protected by a thermally protective layer isolating it from the rocket propellant.
Increasing the steel wall temperature to 350 °C causes a decrease in its mechanical properties of 20%. For comparison, it should be noted that the temperature inside the sustain motor chamber exceeds 3000 °C.

1.1. In-use thermal insulation and the technology of its implementation in the GROM system

Developing the technology for implementating the thermal insulation to the GROM-M system was modelled on the thermal insulation of the sustain motor chamber of the system. The thermal insulation used in the manufacture of GROM is a layered coating consisting of two principal materials:
– a rubber compound sleeve - N-10F-4 rubber compound,
– carbon cloth impregnated with phenol-formaldehyde resin.
In the process, WK-3 glue and an insert made of pressboard are also used in making the thermal insulation.
The general course of the implementation process for insulating the sustain motor chamber consists of:
– manufacturing the rubber sleeve from unvulcanized N-10F-4 compound by extrusion,
– treatment of the carbon cloth with phenol-formaldehyde resin,
– pre-forming the carbon cloth and rubber sleeve composite into the vulcanizing press,
– machining the pre-formed composite to obtain proper dimensions,
– preparing the composite for mounting in the motor chamber,
– cleaning the inner surface of the motor chamber,
– placing the composite thermal insulation in the motor chamber – insertion of a metal core,
– vulcanizing the thermal insulation,
– removal of the core and inspection of the insulation.
Thermal insulation manufactured in this way, provides protection for the motor chamber under the specific conditions of rocket propellant combustion – *i.e.* 8 s at a temperature of about 2700 °C. Thermal insulation made according to this process cannot be applied when higher energy propellant is used, because it does not retain its basic properties – which can be seen in the Figure 1.

Figure 1. The effect of the metal body of the rocket motor being burnt through

2. Modernization of the thermal insulation of a metal rocket motor

2.1. General requirements

BUMAR AMUNICJA S.A. and the IMPiB Institute undertook the development of a new thermal insulation for the motor chamber. An assumption was made that the general principles of the practical implementation of insulation in the motor chamber of the portable GROM-M anti-aircraft system, will be similar to the technology used to date. Issues related to work carried out in modernising the sustainer motor insulation were:

– selection of adhesive for gluing the insulation to the motor chamber;
– selection of components and optimisation of the rubber compound for making unvulcanized rubber sleeves;
– technology for the production of insulating components and technology for manufacturing insulation.

2.2. Selection of adhesive for gluing thermal insulation

The following adhesives were selected for laboratory tests to verify the endurance of the rubber-metal bond and their usability under production conditions:

– two-layer contact adhesives for joining rubber with metal based on rubbers (including chlorinated and chloroprene ones) and resins – primer adhesive OK-I and OKR-35 contact adhesive (composition and formula of adhesives as developed by the Institute),
– OKA-875 ebonite adhesive (composition and formula of the adhesive as developed by the Institute),
– commercial adhesives for bonding rubber with metal: Chemosil 211, Chemosil 411.

Rubber-metal samples were prepared in the laboratory to assess the durability of the rubber-metal bond. These samples were assessed for rubber to metal adhesion using the peel test in accordance with the Polish standard PN-92/C-04252.

Based on the results of the durability of the bond presented in Table 1, the availability of adhesive and technological parameters of adhesives for further tests, the following were selected: Chemosil 211 (primer adhesive) and Chemosil 411 (surface adhesive) as replacements for the WK-3 adhesive.

Table 1. Test results of the bond strength of N-10F-4 compound – metal

No.	Adhesive type	Bond strength [MPa]
1	WK-3 - reference sample	10.4
2	OK-I, OKR-35	9.8
3	OKA-875	1.7
4	Chemosil 211, Chemosil 411	13.6

2.3. Selection of components for the rubber compound for thermal insulation

Formulation of the composition of the rubber compound for manufacturing the thermal insulation of the GROM-M sustainer motor chamber included:
- selecting and optimizing components of the rubber compound,
- testing the properties of compounds and vulcanizers,
- modifying carbon cloth impregnation,
- making samples of thermal insulation and testing their properties.

The selection of rubber compound components was carried out on the basis of previous experience of the IMPiB Institute in this field, especially in terms of reducing the amount of flammable substances.
For the laboratory tests, rubber compounds were prepared with differing types of rubber, types and quantity of filler and other components. Compounds were made from nitrile rubber, nitrile rubber with polyvinyl chloride, and styrene butadiene rubber. As part of the tests, compounds with a reduced content of flammable substances as well as compounds recognized as flame retardant, were prepared. Flame retardant substances in the form of halogen derivatives, antimony(III) oxide and aluminium(III) hydroxide were used. The testing of compounds also allowed for verification of the possibility of using various fillers, such as: magnesium(II) oxide, milled carbon fibre and soot.
The basic properties of selected compounds and vulcanizers were tested. Sampling and testing of thermal insulation in an acetylene torch flame were performed, with measurements of time until the onset of metal colour change (assessed organoleptically) and the time of sample burn-through.
The insulation layer is characterized by the fact that the insulation components undergo a carbonisation process under the conditions of rocket propellant combustion, creating an insulating carbon-carbon phase composite layer which increases motor strength and protects the said metal body from the thermal exposure of rocket propellant combustion. Therefore, the basic parameter characterizing the insulation is its resistance to being burnt through under motor operating conditions. Table 2 shows the results of the length of time needed for the metal colour to change and the rubber-metal samples to burn through.

Table 2. Comparison of rubber–metal samples (without fabric, steel sheet thickness 1 mm)

Sample type	Thickness [mm]	Metal colour change [s]	Burn through [s]
N-10F-4	2.75	15	17
	2.75	11	15.5
GM-5	2.70	8	10.5
	2.70	10	12
GM-9	2.70	9.5	12
	2.70	9	10
GM-14	**2.85**	**14.5**	**16.5**
	2.65	–	–
GM-15	2.70	10	12
	2.60	10	12
GM-16	2.90	5.5	7
	2.85	6	7
GM-17	2.70	10	12
	2.75	10	12
GM-18	2.60	10.5	12
	2.70	9	12
GM-19	2.70	7.5	9
	2.75	7.5	9
GM-20	2.75	7	9.5
	2.85	8	–

Table 2. continuation

Sample type	Thickness [mm]	Metal colour change [s]	Burn through [s]
GM-30	2.95	11	13
	3.05	11.5	13
GM-31	2.90	6	8
	2.95	6	8
R 502/75 silicon	2.65	6.5	8
	2.65	5.5	7.5
GM-32	2.95	8	10.2
	2.85	7.5	9.5
GM-33	2.95	8	9.8
	3.05	7	8

The above results indicate that the GM-14 compound is comparable to the reference compound (N-10F-4). Selected samples were tested using a thermal imaging camera in conjunction with the acetylene torch flame, in order to validate the method. Table 3 presents the numerical results of the thermal imaging, juxtaposed with the parallel quantification of the results assessing the time needed for metal colour change and for burn-through of the sample (in the acetylene torch flame).

Table 3. Investigating metal colour changes and samples being burnt through during thermal imaging

Sample type	Thickness [mm]	Metal colour change [s]	Burn through [s]	Temperature at time of burn-through through [° C]	No. of sample thermal imaging examination
N-10F-4	2.75	15	17.2	1290	1a
	2.75	11	15.5	1216	1b
GM-5	2.70	8	10.5	1191	2a
	2.70	10	12	1150	2b
GM-9	2.70	9.5	12	1268	3a
	2.70	9	10	1055	3b
GM-14	**2.85**	**14.5**	**16.5**	1152	4a
	2.65	–	–	–	4b
GM-15	2.70	10	12	1250	5a
	2.60	10	12	1197	5b
GM-16	2.90	5.5	7	1300	6a
	2.85	6	8.5	1251	6b
GM-17	2.70	10	12	1265	7a
	2.75	10	12	1282	7b
GM-18	2.60	10.5	12	1256	8a
	2.70	9	12	1244	8b
GM-19	2.70	7.5	9	1300	9a
	2.75	7.5	9	1247	9b
GM-20	2.75	7	9.5	1196	10a
	2.85	8	–	1197	10b
GM-30	2.95	11	13	1214	11a
	3.05	11.5	13	649	11b
GM-31	2.90	6	8	431	12a
	2.95	6	8	1236	12b

Table 3. continuation

Sample type	Thickness [mm]	Metal colour change [s]	Burn through [s]	Temperature at time of burn-through through [° C]	No. of sample thermal imaging examination
R 502/75 silicon	2,65	6.5	8	1139	13a
	2.65	5.5	7.5	1225	13b
GM-32	2.95	8	10.2	1150	14a
	2.85	7.5	9.5	1210	14b
GM-33	2.95	8	9.8	1226	15a
	3.05	7	8	1249	15b

Table 3 shows that the GM-14 compound, whose burn-through time is comparable to the reference compound, has a lower temperature at the time of burn-through, which may indicate a higher heat capacity and thus higher thermal stability, compared with the reference compound.

In addition, the thermal imaging results, especially in samples in which burn-through occurred, confirmed the agreement of the sample burn-through time obtained from thermal imaging measurements with the method of "manual" measurement (using stop-watches) of the burn-through time.

Tables 4 and 5 present the results of the burn-through time of 1 mm sheet for various combinations of compounds, fabric layers and fabric impregnation.

Table 4. Burn-through time test results (1 mm sheet – reference compound)

Sample type	Metal colour change [s]	Burn-through [s]	Remarks
N-10F-4 3 layers of fabric with resin	18	23	
	14.5	20	
N-10F-4 3 layers of fabric impreg. with GM-14, 1 side coated with resin	12.5	17	Fabric 1 × GM-14 + 1 side coated with resin
	16	20	
N-10F-4 3 layers of fabric impreg. with GM-35	16.5	20	Fabric 1 x adhesive GM-35
	16	20	
N-10F-4 3 layers of fabric impreg. with GM-35, 1 side coated with resin	**19**	**23.5**	**Fabric 1 × GM-35 + 1 side coated with resin**
		23	

Table 5. Burn-through time **test results (1 mm sheet)**

Sample type	Thickness [mm]	Metal colour change [s]	Burn-through [s]
N-10F-4 reference 3 × fabric resin	2.74	11.5	
	3.04	15	20.5
	2.74	15.5	20
	3.00	16	21.5
N-10F-4 3 × GM-35 fabric 1 × resin	2.85	18	23
	2.88	17	21
	2.88	21	25
	2.90	16.5	22.5
GM-14 3 × GM-35 fabric 1 × resin	**2.83**	**16**	**21**
	2.85	**20**	**23**
	2.83	**19**	**23**
	2.83	**19.5**	**23**

3. Summary

Comparison of results in Tables 2 to 5 demonstrates that in the flame tests, samples using the following materials proved to be better than those from the previous insulation:

– basic variant A: GM-14 rubber compound protected with 3 layers of carbon cloth impregnated with GM-35 compound,
– auxiliary variant B: N-10F-4 rubber compound protected with 3 layers of carbon cloth impregnated with GM-35 compound.

To maintain uniform structure and thermal resistance of the insulation layer in the composition of the impregnating rubber compound, similar components are used: the same type of rubber, the same phenol-formaldehyde resin, the same vulcanizing substances. An additional component of the newly developed rubber compound is chopped carbon fibre, which increases the thermal resistance of the motor compartment's thermal insulation, resulting in the possibility of using higher energy propellant than at present.

Static ballistic tests of rocket motor bodies with thermal insulation made from variant A materials, were carried out – with satisfactory results being obtained.

Figure 2. Rocket motor bodies after static ballistic test: a) with modernized thermal insulation, b) with extant thermal insulation

4. Conclusions

– The developed variants of thermal insulation provide effective thermal protection of the motor compartment during its operation lasting about 11 s at a temperature above 3000 °C.
– The technology developed so far for manufacturing thermal insulation for the GROM system enables the manufacture of a modern thermal insulation for its metal rocket motor.

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