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Propellant Pyrotechnic Mixtures Based on Polytetrafluoroethylene (PTFE)

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Propellant pyrotechnic mixtures based on polytetrafluoroethylene (PTFE) as an oxidant represent a perspective structure of the rocket fuel ignition. In this paper the results of research are presented with characteristics of combustion for different structures based on PTFE as an oxidant and B, Al and Ti as a fuel. By changing the content of the components and their granulation, a myriad of structures is tested along with their characteristics presented in the paper. The possibilities for further researches of pyrotechnic mixtures based on PTFE as an oxidant, are enabled from this paper. It is determined that the characteristics of the mixtures based on Al/PTFE/viton A (Viton A) can be successfully applied with the ignition of certain types of rocket fuels.

Key words: **pyrotechnic mixture, propellant mixture, polytetrafluoroethylene, ignition, rocket fuel, burning rate, burning pressure, burning thrust, thermodynamic potential.**

Introduction

POLYTETRAFLUOROETHYLENE (or PTFE in the paper) is a polymer of tetrafluorethylene synthesized for the first time in 1946 within the laboratories of the Dipon Company in the USA, while its industrial production started sometime afterwards. The characteristics of this polymer and the simplicity of its creation have contributed that this product finds wide application. PTFE is a chemically very stable compound, resilient to acids and alkali, and thermally relatively stable and dissoluble with any type of solvent [1].

At the beginning of the 60s, it was discovered that the PTFE powder mixed with the metal powder of Mg or Al reacts very violently [2, 3]. Since then, in a very short time, an intensive research in conquering the pyrotechnic mixtures based on PTFE as an oxidant has started [4-19]. The first researches were mainly focused on Mg/PTFE mixtures and they were studied the most [4, 5, 6, 8, 15]. These mixtures possess several advantages: high energy potential, low hygroscope, high stability, high degree of safety when producing and handling, simple production (easy to granulate, tablet and press), small dependence of burning rate on temperature and pressure, stabile combustion under low pressures and temperatures. Mg/PTFE mixtures have, in many aspects, better characteristics from the classic mixtures and as such have become very interesting for research. Copolymer vinyldenfluoride and hexafluorpropylene viton A (Viton A) is always added to Mg/PTFE mixtures in order to increase homogeneity and to ease the production and molding. Adding up to 20 % of viton A into the PTFE mixture does not have any significant effect on its characteristics. Because of its initial properties, great stability and a huge number of solid and liquid heated particles in the process of combustion, which allows a “smooth” ignition of the rocket engine with solid fuel [7], the Mg/PTFE/viton A mixtures have already found their application in rocket engine ignition and other purposes (for example as IC baits).

In theory, as a fuel, in PTFE mixtures, besides magnesium, all elements can be found if their connection with the fluor is stronger than the carbon-fluor connection. Mixtures of Al/PTFE, B/PTFE, Ti/PTFE, Si/PTFE and Zr/PTFE are mentioned in literature [4,11,12,15,16,17,18]. There is almost no information about serious experiments with these mixtures, except mentioning that such mixtures exist. In fact, these mixtures are only scarcely mentioned in papers with the subject of Mg/PTFE mixtures, and therefore there are only poor information about their characteristics. However, papers that deal with this subject more thoroughly [15,16,17,18] have appeared lately.

The technology of developing mixtures that are examined in this paper, as well as the methology of their research, is identical to the one used for examining the Mg/PTFE mixture [19].

Theoretical part

Al/PTFE mixtures

Although it was established at the beginning of the 1960s that the reaction between Mg powder and Al powder with PTFE powder is volatile and exothermic, Al/PTFE mixtures were not tested, and Mg/PTFE mixtures were only mentioned in literature. Only during the 1980s, more intensive research works of these mixtures have started and they are still being conducted [9, 15, 16, 17]. Based on known facts about Al as a fuel in pyrotechnic mixtures and literature information about the combustion mechanism for Mg/PTFE mixtures, possible equations of reaction between

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Al, PTFE and viton A are hypothesized.

The reaction that is happening between Al and PTFE for stoichiometric relation of components can be written in the following form:

$$4Al + 3 —(C_2F_4)— \rightarrow 4AlF_3 + 6C$$

if Al is in excess, then the reaction has the following formula:

$$mAl + 3 —(C_2F_4)— \rightarrow 4AlF_3 + (m-4)Al + 6C$$

The reaction for the viton A mixture can be displayed with the following equation:

$$mAl + 3 —(C_2F_4)— + n —(C_5H_{3,5}F_{6,.5})— \rightarrow (n+4)AlF_3 + 3.5nHF + (5n+6)C + (m-n-4)Al$$

The paper [12] mentions termite pyrotechnic mixtures (or termites) that are based on Al and PTFE, but a greater attention is dedicated to the mixtures with viton as a connective tissue. The author mentions that viton A as a connecting tissue even in small amounts (4%) secures very good mechanical characteristics of the mixture. Termite mixtures that contain viton A in large amounts keep their high heat potential, high burning temperatures, and if a viton A is added in large amounts then the mixtures acquire plastic characteristics and they burn from the flame.

Ti/PTFE mixtures

The Ti/PTFE mixtures are mentioned in several papers [6,7,12], which indicate that these mixtures were objects of interest and that they were studied in great detail, although this information is very modest.

The chemical reaction of Ti and PTFE combustion for stoichiometric component ratio can be written in the following form:

$$Ti + —(C_2F_4)— \rightarrow TiF_4 + 2C$$

For the mixtures with the excess of Ti:

$$mTi + —(C_2F_4)— \rightarrow TiF_4 + (m-1)Ti + 2C$$

and for the mixtures that include viton A:

$$mTi + —(C_2F_4)— + n —(C_5H_{3,5}F_{6,.5})— \rightarrow (1+0,75n)TiF_4 + 3.5nHF + (5n+2)C + (m-1-0,75n)Ti$$

In the photographs of burning the Ti/PTFE mixtures [5], a narrow lighting zone can be noticed where the chemical reaction between the fuel and the oxidant is conducted. The burning rate for these mixtures is greater than the combustion of B/PTFE bur smaller than the combustion of Mg/PTFE. This is connected with Ti heat conductivity of 0.1554 J/scmK, which is 10 times greater than heat conductivity for Boron and 10 times less for Magnesium.

Besides the already mentioned [2, 14], in literature even Zn and PTFE mixtures are mentioned, but without the information regarding their structure and characteristics.

B/PTFE mixtures

Besides the Mg/PTFE mixtures, B/PTFE mixtures are the most mentioned in the literature [6,13]. These are only theoretical considerations without any information about experiments and their application.

The chemical reaction of the B/PTFE mixture for the stoichiometric composition is given in an equation:

$$4B + 3 —(C_2F_4)— \rightarrow 4BF_3 + 6C$$

for mixtures with the surplus B:

$$mB + 3 —(C_2F_4)— \rightarrow 4BF_3 + (m-4) B + 6C$$

and for mixtures that include viton A:

$$mB + 3 —(C_2F_4)— + n —(C_5H_{3,5}F_{6,.5})— \rightarrow (n+4)BF_3 + 3.5nHF + (5n+6)C + (m-n-4)B$$

The speed of the chemical reaction with these mixtures (as well as with Mg/PTFE) depends on the burning rate for non-reactive mixtures. The burning rate for non-reactive mixtures depends on heat conductivity of the mixture and heat flux of the flame on its surface. Heat conductivity of the B/PTFE mixture is far lower than the heat conductivity of the Mg/PTFE mixture, since the magnesium heat conductivity (1.544 J/scmK) [20] is more than 100 times higher than the heat conductivity for Boron (0.0126 J/scmK) [20]. The heat conductivity for PTFE is even lower and it is 0.00252 J/scmK [20]. Hence the heat conductivity of the B/PTFE mixture is very low. The speed of heat transferring from the zone of chemical reaction to non-reactive mixture is also very low, and therefore heating of the non-reactive mixture is so weak. That is why the non-reactive mixture reaches very slowly the temperature where chemical reactions of combustion are conducted.

Besides mentioned, the product of the mixture combustion is gaseous by formed BF_3 (vaporization temperature is $-99^{o}C$), which additionally lowers the heat flux from the flame to non-reactive mixture [13], because gas products burn much faster than the non-reactive mixtures that heats up slower to the temperature where chemical reactions are conducted.

The results of the experiments with initiating the mixtures of Mg/PTFE and B/PTFE with the laser beam are given in the paper [13], where a high-powered laser »Coherent Super $48CO_2$ » was used. The experiments were conducted on B-50% PTFE-50% mixture that has 20 ms of initiating delay time while under the radiation flux of $150W/cm^2$. With the increase in radiation flux, the initiating delay time of the mixture is also slightly reduced. The Mg/PTFE mixture with the same component ratio has an initiating delay time of 240 ms for radiation flux of 350 W/cm^2, and it is reduced to 20 ms when the strength of radiation flux reaches 800 W/cm^2. The heat conductivity of the mixture plays an important part in the process of initiating the mixture with the laser beam. As mentioned before, the heat conductivity of the B/PTFE mixture is lower than with Mg/PTFE mixtures. When the laser beam falls onto the surface of the B/PTFE mixture, it generates thermal energy that, due to weak conductivity of the mixture and with fast local heating, enables the mixture to achieve the ignition temperature. By adding only 2% of Boron instead of Mg into the Mg/PTFE mixture, the ignition time delay is reduced, especially in the case of stronger radiation fluxes. In the paper [12], an example is given for the mixture Mg-20% PTFE-50% and B-30% where the ignition delay time for the strength of the flux 150 W/cm^2 is 30 ms (slightly higher than for B/PTFE mixtures) and for the strength of the flux 800 W/cm^2 is 5 ms.

Experimental part

Al/PTFE mixtures

Al/PTFE mixtures are made using the same technology used for developing Mg/PTFE mixtures tested in [19]. Tests of these mixtures were conducted over experiments with the mixture structure effects on the basic characteristics (ignition delay time, burning time, maximum combustion pressure, heat capacity, flame temperature and burning rate). The content of the basic Al and PTFE components is changed, and the structure of the tested mixtures is given in Table 1.

Table 1. Structure of the tested mixtures Al/PTFE/Viton A

Mixture number	Al, %	PTFE, %	Viton A, %
1	18.0	78.0	4.0
2	26.5	69.5	4.0
3	38.0	58.0	4,0
4	48.0	48.0	4.0
5	58.0	38.0	4.0
6	68.0	28.0	4.0

For the development of mixtures, Al granulation bellow 40 μm was used along with the central diameter of the particle close to 8.5 μm. With Al mixtures that had the central diameter of the particle close to 30 μm, the number of failures with initiation was significant, and the mixtures with Al bellow 40% were nearly impossible to initiate with the electric squib EU-25 (made by “Pobjeda” Goražde). The mixtures made from Al that were exposed longer to the oxygen from air, and then coated with homogeneous oxide plate, are also very difficult to initiate. The oxide plate for Al, when compared to the oxide plate for Mg (which is porous), passivize the surface of the particles and protects the metal from further corrosion, and at the same time makes mixture burning more difficult.

The mixtures were tested in 300 cm³ manometer bomb. The mixture in a granular form with the mass of 3 g was charged in a polyethylene bag with the electro-igniting squib EU-25. The pressures were registered via the piezo-sensor Kistler. The results of the research are received in a form of a diagram of pressure in the function of time. Maximum registered pressure, delay time, ignition (time that passes from the moment of releasing the electricity into the electric circuit till the beginning of the pressure increase) and burning time (time that passes from the beginning of the pressure increase till reaching the maximum pressure). The results of testing the mixtures are shown in Figures 1 - 6.

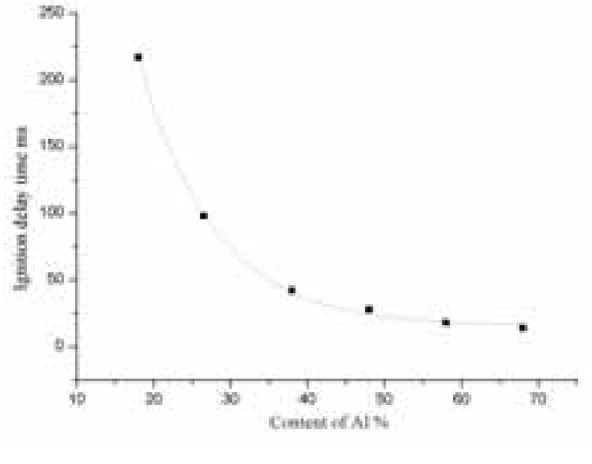

Figure 1. Dependence of the ignition delay time from the content of Aluminum

The characteristics of the mixture burning from Table 1 act similar by with the Mg/PTFE mixture [19]. The ignition delay time of the mixture and the burning rate in the granulating condition (Figures 1 and 2) recede with the increase of Al content. This is explained with the process of heat exchange from the flame to the non-reactive mixture, or from the flames of the electric squib to the mixture. It is known that the heat conductivity for Al and Mg is several times higher than the heat conductivity for PTFE, hence the heat exchange is relieved by increasing the participation of Al. The ignition of the mixture number 1 (Table 1) was very un-reproductive with a large number of failures (about 40%). The ignition was conducted with electric squib EU-25. By increasing the number of Al (mixture number 2 in Table 1), time delay is significantly reduced, and the ignition process went without failures. When compared to Mg/PTFE mixtures, the initiation of the Al/PTFE mixture is far more difficult and with greater time delay.

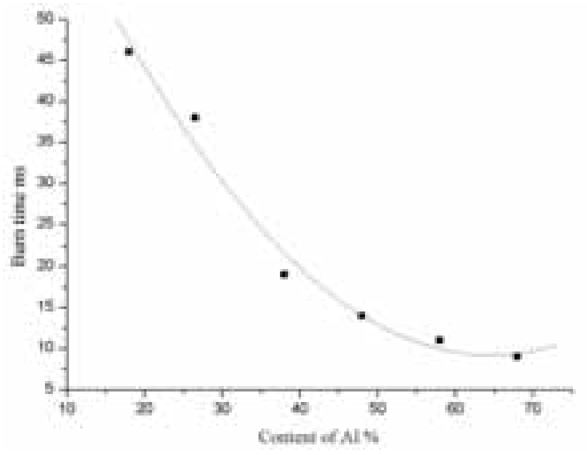

Figure 2. Dependence of the burn time from the content of Aluminum

The IKA Kalorimetar Adiabatich C-400 determines heat potential in an inert atmosphere (argon). The highest values of the head capacity (Fig.4) are not given for the stoichiometric ratio but for Al content of about 40%, and with an increase or decrease of the Al content, the values for head capacity decrease as well. This is not in accordance with the theory (at Mg/PTFE mixtures, the largest head capacity is in the mixtures with the stoichiomertic component ratio). It is possible that burning the Al/PTFE mixture does not occur as in equations given in this paper or most probably, that mixtures with lower than 40% content of Al do not burn completely, which is related to the process of heat transfer to the non-reactive mixture. Since the heat conductivity is lower with the mixtures that have a lower content of Al, it can happen that the part of the mixture does not burns completely, hence the head capacity is smaller.

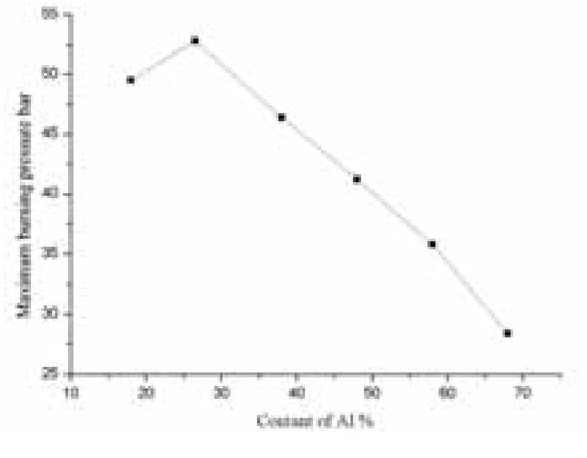

Figure 3. Dependence of the maximum burning pressure from the content of Aluminum

The maximum burning pressure (Fig.3) is lthe highest at the mixtures with the stoichiometric content of components (mixture number 2 in Table 1) and it gradually recedes along with the increase or decrease of the Al content. Combusting Al/PTFE mixtures create pressures higher than with Mg/PTFE for the same loading density.

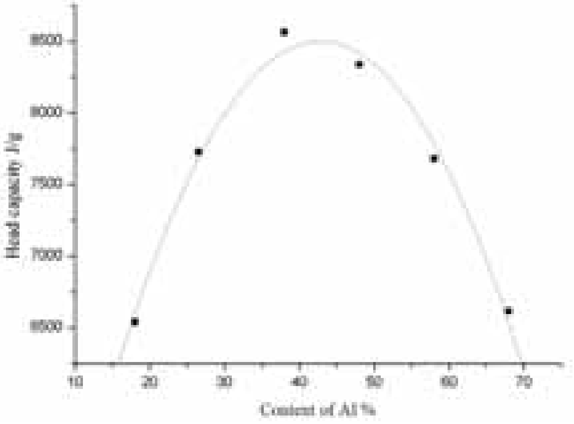

Figure 4. Dependence of the head capacity from the content of Aluminum

The flame temperature is determined by the optical pyrometer FEP HEIM electric DDR from the distance of 2 m. The lens of an optic pyrometer was pointed to the middle of the flame that created *otpresak*? with a mass of 10 g and of 25 mm in diameter. The measuring was conducted when the *otpresak*? blazed about 2 to 3 sec after the ignition. The flame temperature (Fig.5) is highest for the mixture that has the largest head capacity and acts according to the change of Al content.

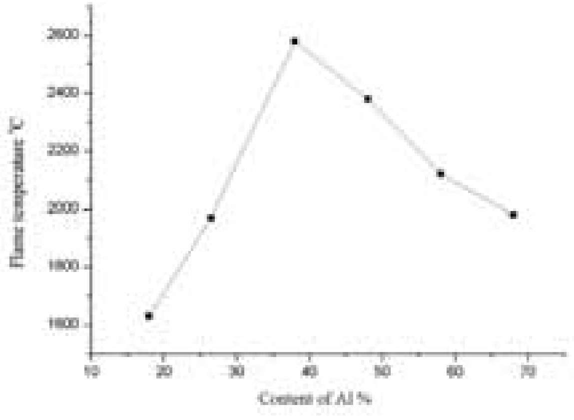

Figure 5. Dependence of the flame temperature from the content of Aluminum

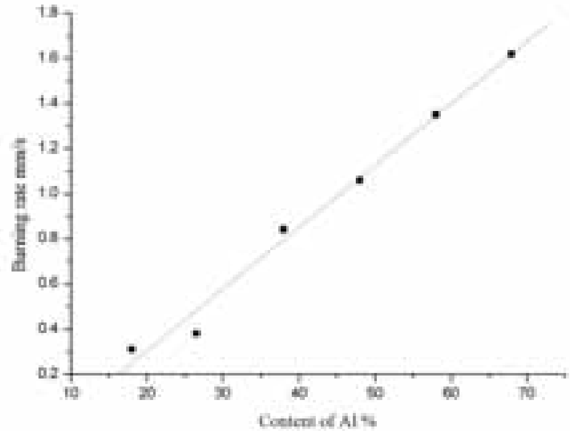

Figure 6. Dependence of the burning rate from the content of Aluminum

The burning rate is determined for the mixtures in a compressed form. The mixtures are pressed into tubes from Al with the diameter of 8 mm and 15 mm long. The burning time is registered on the Digital Oscilloskope Nikolet type 2090 over the photocell Panlux electronic 2 Gossen that measured the light intensity in a function of time. The burning rate calculation was based upon the pipe length and burning time. The burning rate for the Al/PTFE mixture in a compressed form grows along with the increase of the Al content (Fig.6). The burning rate depends directly on the heating rate of the non-reactive mixture, in other words, from heat transfer in the zone of chemical reactions (flames) towards non-rective mixture. Heat conductivity for the mixture increases with the increase of the Al content, and with them also increases the burning rate for the mixture.

The change of the characteristics for Al/PTFE in correlation with the content of the components is similar, with small exceptions, as with the Mg/PTFE mixtures. By some characteristics (burning rate, head capacity and pressure of the products from combustion) these mixtures are better than the Mg/PTFE mixtures. The major defect of the Al/PTFE mixtures is their difficult initiation, especially in the mixtures with massive particles and a lower Al content.

Ti/PTFE mixtures

To develop a Ti/PTFE mixture, the same technology that created Mg/PTFE mixtures [19] and the same research methodology was used as with Al/PTFE mixtures. There was only one type of a Ti granulation bellow 44 μm with the central particle diameter of 13 μm that was available for research of these mixtures. The structure of tested mixtures is given in Table 2.

Table 2. Structure of tested mixtures Ti/PTFE/Viton A

Mixture number	Ti, %	PTFE, %	Viton A, %
1	48,0	48,0	4,0
2	58,0	38,0	4,0
3	68,0	28,0	4,0
4	78,0	18,0	4,0

The mixtures with the Ti content bellow 48% could not be initiated with the electric squib EU-25, therefore these mixtures had to be initiated by the open, slowed mixture (W/$BaCrO_4$), but they burned weakly with the expressed tendency to extinguish. The mixtures with Ti bellow 30% could not be initiated at all.

The results of the examination are presented in Figures 7-12.

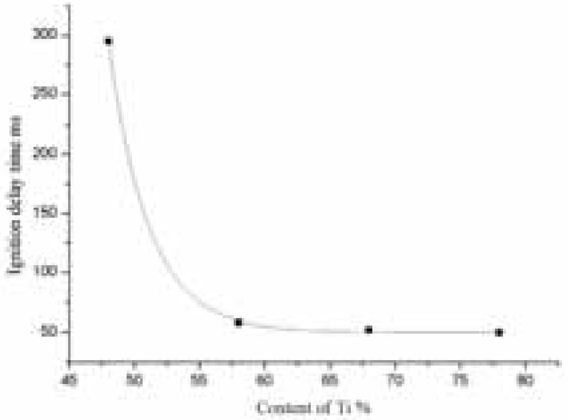

Figure 7. Dependence of the ignition delay time from the content of Titanium

The mixture with a Ti content of 48% is very difficult to initiate with the ignition delay time 295 ms (Fig.7) and a large number of failures occurred (over 60%) with the EU-25. By increasing the Ti content, the initiation is simplified so that the mixtures with 58% of the Ti content initiate without failures and with a relatively small ignition delay time (52.8 ms). The ignition delay time is decreased with the increase of the Ti content, and the mixtures with a very high percent of Ti content and very low percent of the PTFE content again increase the ignition delay time.

The burning time of the mixture in a loose condition is similar (Fig.8) which is understandable since the heat conductivity of Ti is about 10 times smaller than the heat conductivity of Al and Mg. Therefore these mixtures are more difficult to initiate, hence the burning rate in the compressed form is smaller (Fig.12). The burning rate increases with the increase of the Ti content and when the Ti content is about 78%, the burning rate recedes.

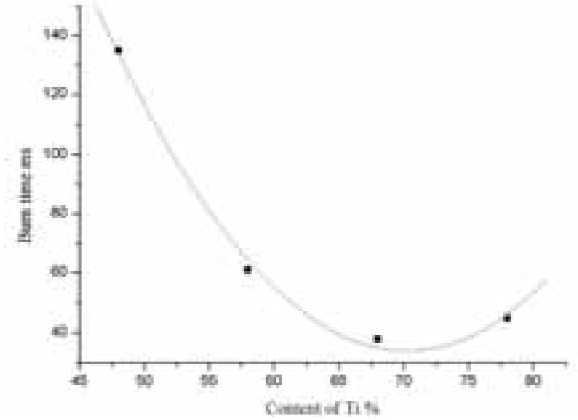

Figure 8. Dependence of the burning time from the content of Titanium

The maximum burning pressure of the mixture (Fig.9) acts similaly like the Mg/PTFE mixture (1) and the Al/PTFE mixture and it decreases with the increase of the Ti content, but it is far smaller than with the above-mentioned mixtures. The head capacity is also smaller (Fig.10) and the flame temperature as well (Fig.11), which recede with the increase of the Ti content. According to [5], the head capacity of the Ti/PTFE mixture for a stoichiometric component ratio is 4939 J/g, but it is not possible to determine the head capacity for that component ratio, because the mixtures with the Ti content bellow 48% did not burn in these experiments.

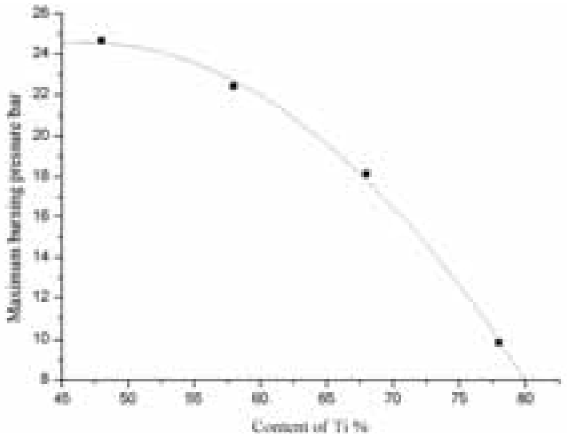

Figure 9. Dependence of the maximum burning pressure from the content of Titanium

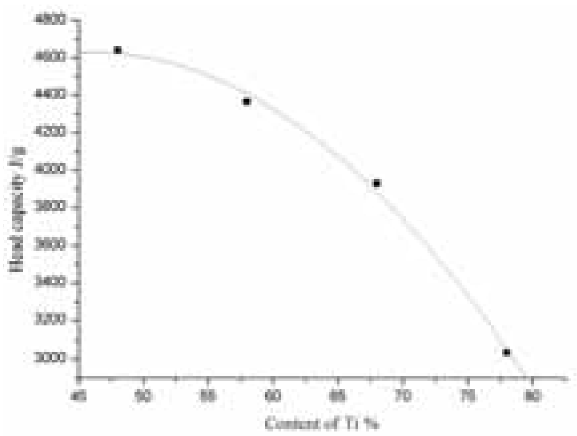

Figure 10. Dependence of the head capacity from the content of Titanium

The characteristics of these mixtures are worse compared to the Al/PTFE and Mg/PTFE mixtures, although there are data [14] that these mixtures are being used in some plastic termites and in IC systems for baits. Further examination of these mixtures would be very interesting, especially from the point of view of applying Ti of smaller granulation.

In paper [5] the mixtures with the content of Ti from 25 % to 80% are tested, and an especially tested mixture is the one with the stoichiometric component ratio (content of Ti 32.4%). However, it was not mentioned which type of Ti was used for the mixture development, nor were mentioned the methods or the types of research of the mixtures in question.

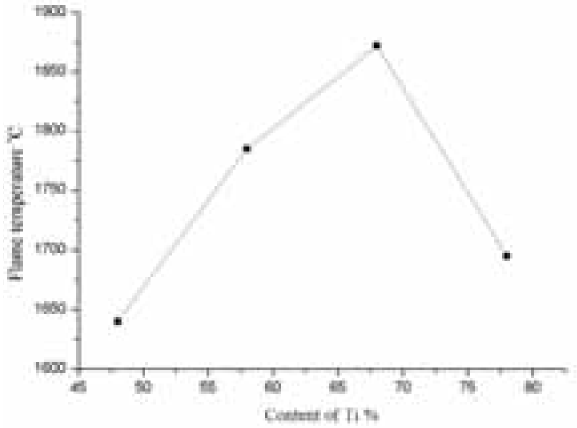

Figure 11. Dependence of the flame temperature from the content of Titanium

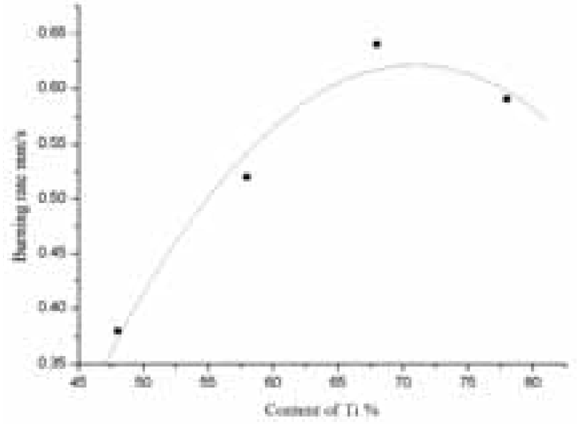

Figure 12. Dependece of the burning rate from the content of Titanium

B/PTFE mixtures

Preliminary research of the B/PTFE mixtures has shown that it is not possible to initiate these mixtures with the electric a squib EU-25, nor with any other type of squib. That is why it is not possible to test these mixtures in a manometer bomb. Three chosen structures for testing are given in Table 3.

Table 3. Structure of the tested mixtures B/PTFE/Viton A

Mixture number	B, %	PTFE, %	Viton A, %
1	12.8	83.2	4.0
2	25.0	71.0	4.0
3	40.0	56.0	4.0

The B/PTFE mixtures, because of the small heat conductivity of the mixture and a large amount of gas products from the process of burning (BF_3 vaporizes on -99°C) cannot burn while in a loose condition. If these mixtures are initiated while in a loose condition, the burning process starts with a big, yellow flame, but soon the burning process is extinguished or it continues to burn over the surface while underneath the non-reactive mixture remains. In fact, because of the small heat conductivity, the heat transfer to the non-reactive mixture is very weak. Also, the products of burning are mostly gaseous, the flame is big and the products of burning quickly estrange from each other, which only makes transfering the heat towards the non-reactive mixture more difficult. Since the mixture is in a loose condition, the empty space between the grains of mixture the only reduces the heat transfer and the preparation of non-reactive mixture for the beginning of the burning reaction and its spreading.

When the B/PTFE mixture is in a compressed condition, the heat transfer is somewhat simplified, hence the mixtures from Table 3 are tested only in a compressed condition and the results are given in Table 4 and Figures 13 and 14 (the test samples and the research methodology were the same as for the Al/PTFE mixtures).

Table 4. Results of testing the B/PTFE mixtures

Mixture number	Flame temperature, °C	Burning rate, mm/s	Ignition temperature, °C
1	~1200	0.10	400
2	~1400	0.14	400
3	~1610	0.25	400

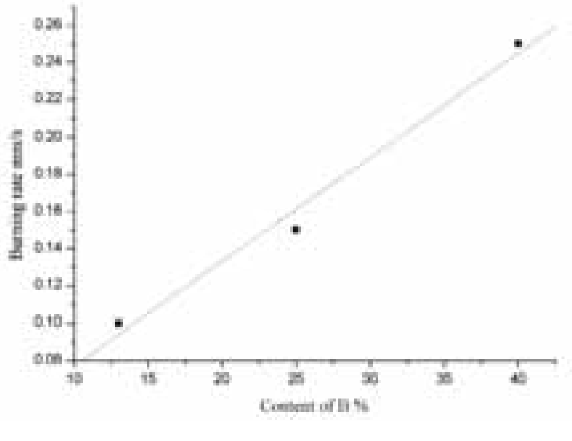

Figure 13. Dependence of the burning rate from the content of Boron

The burning rate is fastest for mixture 3 and that amount is 0.25 mm/s. The mixture in a compressed condition burns very steadily, with a big, yellow flame from which black smoke rises, and it comes from carbon in PTFE. This mixture, even in a loose condition, burns completely with a slightly faster burning rate (0.35 mm/s). The burning rate of the mixture is significantly increased when the burning pressure increases as well (while burning in the manometer bomb), which is understandable since the burning products are in a gaseous state. This method is still under development so there is not enough concrete results.

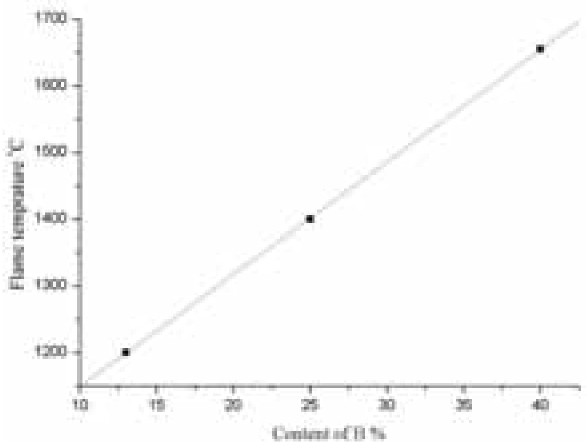

Figure 14. Dependence of the flame temperature from the content of Boron

By increasing the content of B, the burning rate and the flame temperature are increased as well, which is a result of a greater heat conductivity of B than that of PTFE.

According to literature [6, 13], these mixtures are easily initiated. This is confirmed by determining the ignition temperature, which is for all three mixtures about 400°C. The ignition temperature is determined by injecting the mixture (between 20 – 50 mg) into a hole of a metal block heated at a certain temperature. However, there are problems with these mixtures, such as heat transfer and self-sustenance of the reaction and therefore it is not possible to initiate these mixtures with electric squibs.

There is no literature information about the application of these mixtures, and according to the characteristics based on these researches; they are interesting only because of studying the oxidation mechanism with PTFE.

Conclusion

From the displayed theoretical and experimental studying of propellant pyrotechnic mixtures that are based on PTFE as an oxidant, the following conclusions can drawn:

1. The pyrotechnic mixtures Al/PTFE/viton A are similar to the pyrotechnic Mg/PTFE/viton A by their characteristics. The maximum burning pressure that Al/PTFE/viton A mixtures develop inside the manometer bomb, the head capacity and the flame temperature are higher those of magnesium mixtures, while their burning rate is lower. The characteristics of the mixture that posses an increased content of aluminum change similarly like those of Mg/PTFE mixtures, or in other words, they depend directly on the heat conductivity of the mixture. The biggest defect of these mixtures is their initiation, which is very difficult because most of electric squibs cannot be initiated while in a loose condition, especially if the content of aluminum is below 40%. These mixtures would be very perspective in terms of application if their initiation problem is solved. It is necessary to supplement these research works with the examination of the effect of the size of aluminum particles on the functional characteristics of the mixture.

2. The heat conductivity for Titaniuma is 10 times smaller than the heat conductivity for Magnesium and this defines the characteristics of these mixtures. Head capacity, maximum burning pressure, burning rate and flame temperature are lower than for mixtures with aluminum and magnesium, and their changes with added content of titanium in the mixture are similar. The mixtures with the content of titanium below 48% could not be initiated. Considering that in literature [6] there is information about the characteristics of the mixture with the content of titanium below 48%, it is assumed that the granulation of the titanium plays a major role. Only one type of titanium granulation was available for the experiments, and therefore the tests with other types of titanium granulation should be repeated.
3. The B/PTFE/viton A mixtures, because of the small heat conductivity of boron (100 times smaller than magnesium), are very different from other mixtures because of their characteristics. These mixtures cannot be initiated with an electric squib of any type. If they are initiated while in a loose condition, big flames burn across the surface with the tendency to extinguish, because the heat directing towards the non-reactive mixture is very weak. Burning of these mixtures while in compressed condition is much stable because the burning of the non-reactive mixture is helped by burning particles. According to literature information [13], B/PTFE/viton A mixtures are very easily initiated and this is why boron is added to other mixtures (Mg/PTFE and Al/PTFE) for the sake of easier initiation, however that reaction, due to small heat conductivity, is not self-sustainable. For now, these mixtures do not have a perspective for practical application, but they are very interesting from the point of view of studying burning mechanisms of pyrotechnic mixtures based on polytetrafluoroethylene as an oxidant.

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Pirotehničke pripalne smeše na bazi politetrafluoretilena (PTFE)

Pirotehničke pripalne smeše na bazi politetrafluoretilena (PTFE) kao oksidansa predstavljaju perspektivne sastave za pripaljivanje raketnih goriva. U ovom radu prikazani su rezultati ispitivanja karakteristika gorenja različitih satava na bazi PTFE kao oksidanasa i B, Al i Ti kao goriva. Variranjem sadržaja komponenti i njihove granulacije ispitana je široka lepeza sastava čije su karakteristike prikazane u ovom radu. Ustanovljeno je da se smeše na bazi Al/PTFE/viton A (fluorel) po svojim karakteristikama mogu uspešno primenjivati kod pripaljivanja određenih tipova raketnih goriva.

Ključne reči: **pirotehnička smeša, pripalna smeša, politetrafluoretilen, pripaljivanje, raketno gorivo, brzina sagorevanja, pritisak sagorevanja, termodinamički potencijal.**

Пиротехнические воспламенительные смесы на основании политетрафторэтилена (ПТФЭ)

Пиротехнические воспламенительные смесы на основании политетрафторэтилена (PTFE) в роли окислителя представляют перспективные структуры для воспламенения ракетных топлив. В этой работе показаны результаты исследований характеристик сгорания различных структур на основании PTFE в роли окислителя и B, Al и T_i в роли топлива. Разнообразием содержания составляющих и их гранулирования исследован широкий веер структур, чьи характеристики показаны в этой работе. Настоящей работой созданы возможности для будущих исследований пиротехнических смесей на основании PTFE$ в роли окислителя. Установлено, что смесы на основании Al-PTFE-витон A (фторел) по своим характеристикам возможно успешно употреблять у воспламенения определённых типов ракетных топлив.

Ключевые слова: Пиротехническая смесь, воспламенительная смесь, политетрафторэтилен, воспламенение, ракетное топливо, скорость сгорания, давление сгорания, термодинамический потенциал.

Les mélanges pyrotechniques d'allumage basés sur polytétrafluoroéthylène

Les mélanges pyrotechniques à la base de polytétrafluoroéthylène (PTFE) comme oxydant représentent les compositions perspectives pour l'allumage des propergols. Dans ce papier on a présenté les résultats des essais sur les caractéristiques de combustion de différentes compositions basées sur PTFE comme oxydant et B, Al et Ti comme combustible. En changeant le contenu des composantes et leur granulation, on a examiné une large gamme de compositions dont on a présenté les caractéristiques dans cet article. Ce travail a donné les possibilités pour les futurs recherches sur les mélanges pyrotechniques à la base de PTFE comme oxydant. On a constaté que les mélanges basés sur Al /PTFE/viton A (fluorel) peuvent être utilisés avec succès, grâce à leurs caractéristiques, au cours de l'allumage de certains types de propergols.

Mots clés: **mélange pyrotechnique, mélange d'allumage, polytetrafluoroéthylène, allumage, propergol, vitesse de combustion, pression de combustion, potentiel thermodynamique.**