QUALIFICATION OF A NEW IM COMPOSITION AND FIRST EVALUATION IN 90MM HESH-T AMMUNITION

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ABSTRACT

Leader in energetic materials, EURENCO has developed a complete range of insensitive explosives, manufactured at full and cost-effective industrial scale.
For pressed applications, EURENCO has developed an optimized IM composition based on NTO and RDX and a specific binder, the composition P16945. This composition is an alternative to the composition A3 with similar performances and better IM properties.
This composition has been fully qualified according to the STANAG 4170.
MECAR SA, a subsidiary of NEXTER SYSTEMS, has developed a process for pressing the P16945 IM explosive into a 90mm MK8 HEP projectile.
MECAR has evaluated the static and dynamic performances of the round and is currently performing several IM testing according to STANAG4439.
This paper will present the results obtained by EURENCO and MECAR in term of characteristics, performance and vulnerability.

1- INTRODUCTION

MECAR SA, a subsidiary of NEXTER SYSTEMS, develops and produces medium and large caliber ammunition for land forces.

MECAR intends to upgrade the High-Explosive Squash Head (HESH) family for the 90mm CKL MK8, 105mm L7 and 105mm M68 guns in order to fulfil the IM requirements. One of the elements which needs to be addressed is the replacement of the explosive loaded in the shells by a low vulnerability explosive. This study is only focused on the replacement of the explosive filling and warhead behaviour to external stimuli.

The current explosive used in this application is a composition A3. The explosive is pressed inside the body. The main objectives of this project were:

-To find a pressable IM composition which can be processed with the current equipment in production, that means at ambient temperature and without using a vacuum process.
-To find an alternative to the composition A3 with similar performances and IM properties according to STANAG 4439.

As leader in energetic materials, EURENCO develops and supplies IM solutions, from IM high explosive (HE) compositions to cast-cure compositions. EURENCO IM HE compositions are based on less sensitive explosives such as TATB (Triamino Trinitro Benzene), NTO (3-Nitro-1,2,4 Triazol 5-One), GUDN or FOX 12 (N-Guanylurea dinitramide), DADNE or FOX 7 (1,1- diamino-2,2-dinitroethylene).

These less sensitive explosives can be used alone or mixed with RDX or HMX to offer the most efficient IM solutions matching all functional requirements (processability, performance and cost). EURENCO has developed a pressed IM composition, called the P16945, based on NTO, RDX and a specific binder. This composition has been designed so that it can be loaded in ammunitions using current pressing capabilities as MECAR for both the 90mm and the 105mm HESH ammunition.

This paper will describe the work done by Eurenco and MECAR in order first to develop and qualify the composition, then to characterize the 90mm MK8 HESH warhead loaded with this less sensitive explosive in term of initiation and performance. First IM tests undertaken in this study, and which are described in this paper, are the bullet impact and the fast cook-off tests. The tests results will give a first overview of the IM signature of the warhead.

2- DEVELOPMENT OF THE COMPOSITION

2.1- State of art IM pressed compositions

Conventional pressed compositions are mostly RDX or HMX based compositions such as composition A3 (91% RDX) or PBXN5 (95% HMX).

In the field of IM compositions, PBXN7 and V350 based on TATB are well known and are produced on an industrial scale. However the TATB cost might restrain further development of these compositions.

Since EURENCO has been producing NTO on an industrial scale for many years, it made it economically interesting to develop new IM pressed compositions based on NTO. P15636, based on NTO and HMX, is already known and characterized against some of the EIS tests, but has never been evaluated in ammunition.

The objective of the work, performed these last years in EURENCO, is to develop a new IM NTO based composition which may be used as a replacement for composition A3.

2.2- EURENCO strategy

EURENCO strategy is as follows:

- Production of NTO based compositions, with different ratios of RDX, in order to fulfil both the IM and functional requirements
- First characterizations of these compositions (safety characterizations, performance, behaviour towards shock, functional characterizations)
- Choice of a composition to be IM characterized.

2.3- Development work

Five different compositions have been prepared, at lab scale, with an increasing percentage of RDX (from 0% to 65%) and named RDX0 to RDX65 in the following paragraph. The binder content was set to 5% for all compositions.

These compositions have been characterized and compared to composition A3 in terms of :

- Safety (table 1)
- Performance (table 2)
- Shock sensitivity (table 3 and figure 1)
- Mechanical properties (table 4)

The objective is to find the best compromise between the performance and the sensitivity of the compositions.

Safety data

Impact sensitivity and friction sensitivity were measured by the BAM test procedure.
As expected the impact sensitivity is driven by the presence of RDX.

Table 1 : Safety data for pressed NTO based compositions

Composition			Impact sensitivity (J.)	Friction sensitivity (N.)
A3	RDX/Wax	91/9	6-15	256
RDX0	NTO/Binder	95/5	39	0+/30 at 353
RDX20 (P16945)	NTO/RDX/Binder	75/20/5	16	7+/30 at 353
RDX30	NTO/RDX/Binder	65/30/5	9	0+/30 at 353
RDX50	NTO/RDX/Binder	47.5/47.5/5	19	0+/30 at 353
RDX65	NTO/RDX/Binder	30/65/5	9	0+/30 at 353

Performance data

The detonation velocity was calculated by Cheetah code v2.0 and the critical diameter was measured according to NF T 70-701 (French norm) for all five compositions.
For compositions with higher RDX content, the critical diameter is less than 5 mm. For RDX20, the critical diameter is between 5 and 7 mm.

Table 2 : Performance data for pressed NTO based compositions

Composition			Critical diameter (mm)	Detonation velocity (m/s)	PCj (GPa)
A3	RDX/Wax	91/9	2.2[1]	8470	29.9
RDX0	NTO/Binder	95/5	> 20	8250	28.7
RDX20 (P16945)	NTO/RDX/Binder	75/20/5	5-7	8350	29.7
RDX30	NTO/RDX/Binder	65/30/5	< 5	8410	30.2
RDX50	NTO/RDX/Binder	47.5/47.5/5	< 5	8470	30.4
RDX65	NTO/RDX/Binder	30/65/5	< 5	8570	31.7

[1] MSIAC Database.

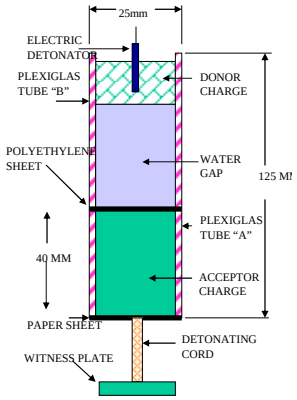
Shock sensitivity

Since the Small Scale Water Gap Test (SSWGT according to STANAG 4488A) can be a good approach to the insensitiveness, this test was performed on all five compositions. We do consider that the limit for insensitiveness is 15 mm, and the composition RDX20 passes the test. However the compositions with the higher content of RDX fail.

Table 3 : Shock sensitivity of pressed NTO based compositions

Composition			SSWGT (mm)
A3	RDX/Wax	91/9	≈ 20
RDX0	NTO/Binder	95/5	No go
RDX20 (P16945)	NTO/RDX/Binder	75/20/5	14
RDX30	NTO/RDX/Binder	65/30/5	16
RDX50	NTO/RDX/Binder	47.5/47.5/5	18
RDX65	NTO/RDX/Binder	30/65/5	19

Figure 1 : Small Scale Water Gap Test



Mechanical properties

The mechanical properties were measured at room temperature on 14 mm pellets pressed at 2525 bars (Uniaxial compression at 1 mm/mn). The porosity of the pressed pellets are of the same level for the pressed NTO based compositions and composition A3.
The mechanical properties are comparable.

Table 4 : Mechanical properties of pressed NTO based compositions

Composition			Density at 2525 bars	Porosity (%)	Stress (Mpa)	Strain (%)
A3	RDX/Wax	91/9	1.615	3.3	7.0	6.0
RDX20 (P16945)	NTO/RDX/Binder	75/20/5	1.836	2.5	8.6	5.2
RDX30	NTO/RDX/Binder	65/30/5	1.812	3.1	7.9	6.9
RDX50	NTO/RDX/Binder	47.5/47.5/5	1.799	2.8	7.3	6.6
RDX65	NTO/RDX/Binder	30/65/5	1.761	4.3	6.5	6.3

2.4- Conclusion

The best compromise between insensitiveness and performance has been found in composition RDX20 which shall be referred to as P16945.
P16945 is comparable to composition A3 in terms of performance and functional requirements (see table 6)

Due to its characteristics, P16945 is a good candidate for IM pressing application.

3- QUALIFICATION OF P16945 ACCORDING TO THE STANAG 4170

The composition P16945 has been fully characterized according to the STANAG 4170. The main results are reported in the paragraphs below.

3.1- Detonation performance

The detonation velocity and critical diameter were measured. The detonation pressure was evaluated based on the density 1.82. The results are given in a following table.

Table 5: Detonation performance results

	Composition P16945	Composition A3
Detonation velocity	7920 m/s	8470 m/s – calculated
Critical diameter	8 mm	2.2 mm
Detonation pressure	28.5 GPa	29.9

The increase of critical diameter can be linked to the IM behaviour of the composition. The lower level of RDX in the composition P16945 explains the lower detonation velocity compared to composition A3. At the end, thanks to the relative high density, the detonation pressure of composition P16945 is similar to the more sensitive composition.

3.2- Sensitivity

Characterization in term of friction, impact and thermal sensitivity are detailed in the table 8. STANAG procedures were applied for any test.

Table 6 : Sensitivity data

	Composition P16945	Composition A3
Impact sensitivity (J.)	10 J	6 – 15 J
Friction sensitivity (N.)	2+ /30 at 353N	256 N
Self-ignition temperature (°C)	209°C	214°C
Combustion under confinement	No explosion	Not evaluated
Gap test (ISGT)	180-190 cards	265 cards

Sensitivity data are comparable with results obtained at lab scale during development work. The Gap test result shows a major improvement to strong shock behaviour : it is equal to standard cast-cure RDX based compositions.

3.3- Mechanical properties

Mechanical properties were performed on the pressed composition. Results show normal decrease of stress and strain from -45°C to +70°C.

Table 7 : Mechanical properties results

Temperature	Sm (MPa)	E (N)	em (%)
-45°C	19,9	6328	7,3
+20°C	6,2	1975	5,4
+70°C	4,0	1287	5,1

3.4- Ageing

The product was aged, during 6 months at 60°C, under normal pressure and hygrometry. Mechanical properties, friction and shock sensitivities as well as thermal signature by differential scanning calorimetry were performed. The details are given in the following tables.

Table 8 : Comparative data at T=0 and after ageing on mechanical properties

	T=0			After ageing		
Temperature	Sm (MPa)	E (N)	em (%)	Sm (MPa)	E (N)	em (%)
-45°C	19,9	6328	7,3	22,2	7042	7,1
+20°C	6,2	1975	5,4	6,3	2005	5,5
+70°C	4,0	1287	5,1	4,2	1331	4,6

Table 9 : Comparative data at T=0 and after ageing on friction and shock

	T=0	After ageing
Friction sensitivity (N.)	2+ /30 at 353N	6+/30 at 353 N
Shock sensitivity (J.)	10 J	8J

Table 10 : Comparative data at T=0 and after ageing on thermal signature

	T=0	After ageing	
Temperature (°C)	200 (onset)	202 (onset)	Melting of RDX
Energy (J/g)	-23	-19	

Temperature (°C)	205 (onset)	206 (onset)	Decomposition of RDX
Energy (J/g)	2193	1754	

The composition P16945 keeps its properties and its integrity after ageing.

3.5- Conclusion

The composition P16945 presents good detonic performance and low sensitivity especially for the Gap Test which is as expected for an IM composition. Moreover, the mechanical behaviour is excellent within the complete temperature range and the composition is stable during aging.
Finally, the composition has been proved to be an IM qualified pressable composition.

4- INDUSTRIAL SCALE-UP OF THE COMPOSITION

4.1- Eurenco capabilities

Eurenco is able to produce from small scale to mass production with :

- Laboratories
- Pilot workshop
- Multi-purpose units
- Large scale facilities

4.2- Production of P16945

After development at laboratory scale, P16945 has been produced at pilot scale.
Since 2013, P16945 has been manufactured at large scale in the industrial production facility. About 600 kg are produced per batch.

Figure 2 : Large scale in industrial workshop

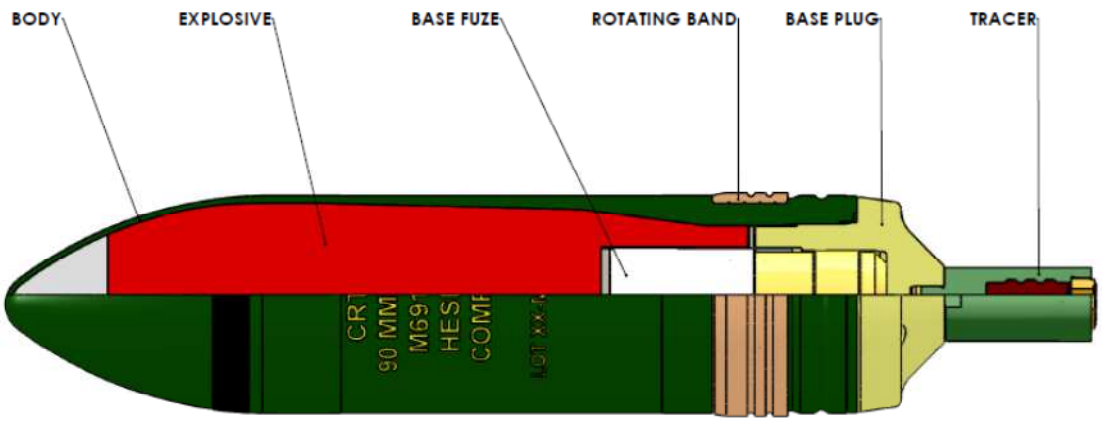
5- LOADING P16945 IN AMMUNITION

5.1- Description of 90 mm MK8 HESH

The 90mm MK8 HESH complete round is represented below. The projectile warhead contains about 2 kg of composition A3 explosive.

Figure 3 : 90mm MK8 HESH-T M691A2 Cartridge

Figure 4 : 90mm MK8 HESH-T M691A2 Projectile



5.2- Pressing process description

MECAR has a facility for pressing explosives which consists of a 350 ton computer controlled press. This double-acting press is used for the loading of HESH and HEAT warheads.

Figure 5: 350 ton computer controlled press

For large caliber ammunition, the explosive, mainly composition A3, is pressed in different steps or increments. The setup of the process is not easy as the explosive charge must have a uniform density all along the body, with a given volume.
Before using the capability of the production unit with the IM P16945, some pressing trials have been performed in order to assess the explosive pressing capability and to reach the desired density.
To reach the IM performances of the composition P16945, a density of 1.8g/cm³ minimum after compression must be reached with the pressing capabilities that are currently used in Mecar.

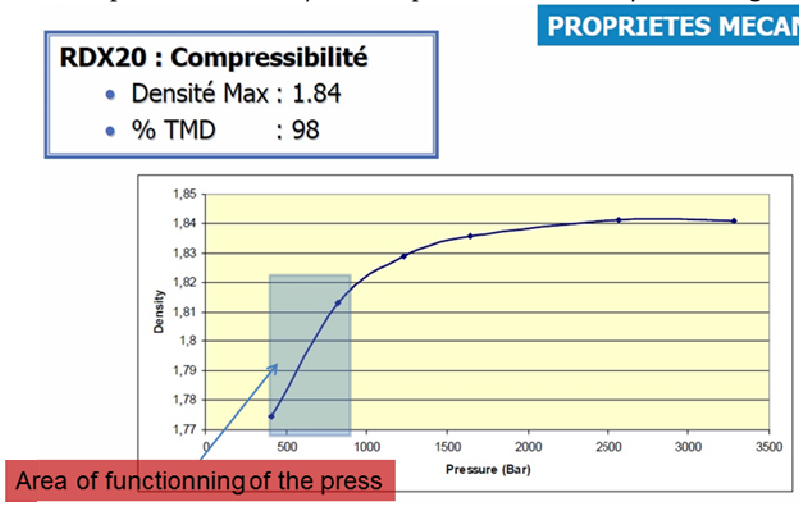
Based on this requirement, the evaluation of the process of compression has been performed by Mecar in two phases:

- Manufacturing of boosters with diameter of 30 mm; weight between 30 and 35 grams.
- Loading of 90 MK8 HESH-T M691A2 with the IM explosive P16945; weight of loading : 2.2 kg

Manufacturing of boosters with diameter of 30 mm

Boosters have been manufacturing with the use of a hydraulic pressing machine at ambient temperature and without vacuum. Different pressures have been applied to determine a compression (density vs pressure) curve and they have been compared to the compression curve of the explosive supplied by Eurenco.
The results were very promising and in line with the requirements. Densities of between 1.77 g/cm³ and 1.82 g/cm³ have been achieved in these conditions; the graph presented below shows the functioning area of the press and compares it to the compression curve of the explosive.

Graph 1: Compression curve of the composition P16945 - functioning area of the press



Loading of 90 MK8 HESH-T M691A2 with P16945 composition

The loading of 90 MK8 HESH-T M691A2 is done in different increments that are pressed in different steps at ambient temperature and without vacuum. Each steps of compression consists of loading the shell with a defined amount of raw explosive which is then pressed into the body.

The objectives for the test of loading are:

- To reach a density of 1.8 g/cm³ in all the increments of explosive,
- To avoid the deformation of the body after loading. To check that no deformation occurred, a go no-go gauge is used after each step of compression.
- To have a good adhesion between the explosive and the inner wall of the body.

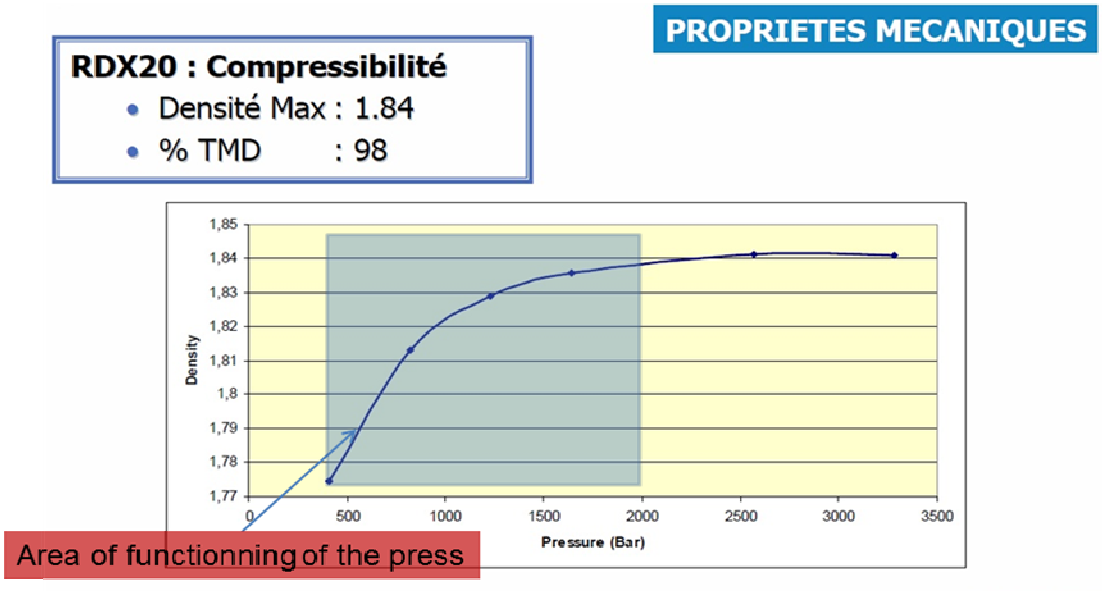
The weight of explosive P16945 contained in the projectile is approximatively 2.2 kg. To set up the process, many iterations have been done with different weights of loading and pressures of compression.

The density of the explosive, loaded in the shells, is measured after the cutting of one body. The density is checked in each section of the projectile, which corresponds to an increment that has been pressed. The pictures, presented below show the shells after cutting and also the increments after compression.

Figure 6: Cutting of a shell

Once the process has been established, the average density has been measured and was higher than 1.8 g/cm³ for each test campaign. No deformations of the shells were observed and the adhesion between the explosive and the inner wall of the shell was good.
Looking at the pressure of functioning of the press and the density observed, a performance area of the press was established and compared to the compression curve of the explosive showing the easy processeability of the explosive with the existing press machine.

Graph 2: Compression curve of the composition P16945 - functioning area of the 350 ton press



With these excellent results, the validation of the use of the explosive P16945 has been completed and the program of tests to establish the static, dynamic and vulnerability characteristics has been continued.

6- PERFORMANCES

To evaluate the performance of the 90 MK8 HESH-T M691A2 loaded with composition P16945, the ammunition must be verified in dynamic and vulnerability tests. These tests have been performed after the validation of the pyrotechnic chain of initiation of the main charge in a static way.

6.1- Dynamic tests

The objective of the dynamic test is to determine if the 90 MK8 HESH-T M691A2, loaded with the composition P16945, meets the requirements of the specification of the standard ammunition loaded with a composition A3.

The specification mentions the following criteria for the performance of the ammunition against a double reinforced concrete wall (following ITOP 5-2-503):

"The 90mm MK8 HESH-T M691A2 shall create an opening in a double reinforced, 20cm thick, concrete wall at 60 meters minimum from the muzzle. The opening shall be 60cm wide by 120cm high (threshold) and 75cm wide by 125cm high (objective). The opening shall have all reinforced bars severed or effectively moved out of the opening. The opening shall be achieved with 5 rounds (threshold); 4 rounds (objective)."

The test has been performed with 90 MK8 gun (1st picture). The distance between the gun and the wall is 60 m (3rd and 4th picture). The ammunition tested is a 90 MK8 HESH-T M691A2 (2nd picture) and 5 rounds have been fired during the evaluation test.

Figure 7: 90 MK8 gun (1st picture), 90MK8 HESH-T ammunition (2nd picture), gun and target (3rd and 4th picture)

After 4 shots, the opening of the hole in the wall was 125 cm height and 135 cm width. The objective is reached. This table gives the dimensions of the hole after each shot.

Table 11 : Dimensions of holes after shots

Shot number	Dimension of the hole – Horizontal (cm)	Dimension of the hole – Vertical (cm)
1	50	50
2	76	100
3	87	120
4	135	125
5	160	158

The pictures show the evolution of the dimensions of the hole after each round.

Figure 8: Shot n°1 (1st picture), Shot n°2 (2nd picture), Shot n°3 (3rd picture) and Shot n°4 (4th picture)

Figure 9: Functioning of the projectile against the wall

The test has demonstrated that the 90 MK8 HESH-T M691A2, loaded with composition P16945, meets the requirement of the specification. With those results, the vulnerability tests can be performed.

6.2- Vulnerability tests

The explosive for the IM replacement of composition A3 must achieve the IM requirements according to STANAG 4439.
At this stage of the development, Mecar has performed a limited evaluation of the IM performance of the projectile with Fast Cook Off and Bullet Impact tests.

6.2.1- Fast cook-off test.

The fast cook-off test has been realized with LPG as the fuel. The ammunition has been placed on the test rig, as shown below. Height thermocouples have been placed at 50 mm from the test object and four blast pressure gages were used, two at 5 and two at 15 m with an angle of 90°.

Figure 10: Projectile on the test bench before test (1st and 2nd pictures),Projectile after the test (3rd and 4th pictures)

The result of the test is a type V reaction. The object has been opened by a pneumatic explosion mechanism and the explosive, contained in the projectile, has been completely consumed by burning. The projectile has been recovered close to the test equipment.

6.2.2- Bullet impact test.

The test has been performed following STANAG 4241. A 12,7 mm bullet has been fired to impact the middle of the projectile at a velocity of 850 m/s. The pictures show the shell after and before the test.

Figure 11: Projectile before test (1st picture), Projectile after test (2nd picture)

The reaction observed is a type V reaction as a burning of some explosive during a few milliseconds has been observed after the bullet has travelled through the projectile. The test object opened also due to this reaction. It has been recovered still containing two thirds of unreacted explosive. The rest of the explosive has been ejected out of the body.

6.2.3- Conclusion of the vulnerability tests.

The first IM tests performed on the projectile 90 MK8 HESH-T, loaded with composition P16945, gives results in line with the requirements. The program of IM tests will continue and must be completed. For the other IM tests, we expect promising results.

7- CONCLUSION

EURENCO has designed an IM pressed composition in order to replace composition A3. Based on EURENCO development work laboratory scale, the composition P16945 presents the best compromise between performance and IM properties. EURENCO has qualified the composition P16945 according to the STANAG 4170 and performed the scale-up to mass production.

This qualified composition has been tested and loaded by MECAR, in 90 mm MK8 ammunition using the current pressing facilities, as a replacement for composition A3. Dynamic tests proved that the performance of P16945 is similar to the composition A3. The first IM tests performed with composition P16945 are in line with the requirements - Type V for FCO and BI - and look promising for the remaining IM tests.