MATEC Web of Conferences **389**, 00021 (2024) https://doi.org/10.1051/matecconf/202438900021
SESAM 2023

Evaluation of the effects produced by triggering pyrotechnic articles for automotive use by exposure to various hazardous external stimuli

Bogdan Garaliu-Bușoi[1,*], *Ștefan* Ilici[1], *Aurelian* Nicola[2], *Claudius* Popescu[3], *Dan* Pintilie[4]

[1]National Institute for Research and Development in Mine Safety and Protection to Explosion –INSEMEX Petrosani, Department of Safety of Explosion and Pyrotechnic Articles, G-ral V. Milea Street 32-34, Petrosani, Romania, insemex@insemex.ro

[2]University of Petrosani, Universitatii Street 20, Petrosani, Romania, aureliannicola@upet.ro

[3]University of Petrosani, Doctoral School, Universitatii Street 22, Petrosani, Romania, claudiusandrei@yahoo.com

[4]University of Petrosani, Doctoral School, Universitatii Street 22, Petrosani, Romania, danpintilie@upet.ro

Abstract. The object of the evaluation of the risk factors that may lead to the accidental initiation of the semi-finished products containing pyrotechnic articles in the process of handling / use / storage / transport is represented by the estimation and assessment of the risk of initiation / detonation of pyrotechnic devices, based on the quantification of the dangers specific to the operations with these types of products, carried out in various phases of the technological flow, used in the manufacture of electrical circuit breakage subassemblies in motor vehicles. Protection against detonation due to accidental initiation is of particular interest to safety because these detonations endanger the life and health of workers as a result of the uncontrollable effects of deflagration and pressure, the presence of toxic reaction products and the consumption of oxygen from ambient air, which workers must inspire. Accidental initiation / detonation of the pyrotechnic actuator can occur by exposing it to the following dangerous external stimuli: electrostatic charge/electrical discharge – with a potential greater than 25 kV; stray currents when passing a current of 0.4 A through the two actuator initiation pins; temperature – higher than 165 ^{o}C; mechanical shock.

1 Introduction

* Corresponding author : bogdan.garaliu@insemex.ro

Safety protection against detonation due to accidental initiation is of particular interest for safety because these detonations endanger the life and health of workers as a result of the uncontrollable effects of deflagration and pressure, the presence of toxic reaction products and the consumption of oxygen in ambient air which workers must breathe. At the same time, it should be borne in mind that material losses caused by explosions can be especially high [1],[2],[3],[4].

1.1 Estimating the possible effects of an explosion

The effects of an explosion are determined by: flames; thermal radiation; pressure waves; projected scrap; hazardous releases of other materials.

1.2 Estimating the dynamic effects of an explosion

In order to create an image of the dynamic destructive effects and the degree of human injury, generated by accidents caused by explosions, it is presented from the specialized literature, in Table no. 1.1 the dynamic effects found on constructions and in Table no. 1.2 effects – trauma inflicted on humans, depending on the overpressures applied, although other factors, such as the notable impulse, may play an important role in these effects.

Following the correlation of the degree of human injury, depending on the overpressure in the shock wave front, the literature specifies as "maximum permissible limit" of overpressure for humans the value of 0.2 bar.

As can be seen from the above data, man is particularly resistant to the action of shock waves. The main cause of injury to people in the area of action of the pressure front is not the pressure in the wave front, but the air current moving after it, whose speed reaches 60 - 80 m / s, for pressures of 0.3 - 0.4 bar. Man cannot resist such current speeds, and with all the short duration of the current, he causes trauma as a result of falling and crashing into rigid surfaces. In addition, shrapnel usually moves after the shock wave, fragments of destroyed objects that cause trauma.

Table 1.1. Dynamic effects of an explosion on construction

Overpressure in shockwave front, (bar)	Effect
0,04 - 0,07	Broken windows, sometimes dislocations of wooden frames
0,07 - 0,15	Cracks and bends (bends) of gypsum walls; the case of asbestos-cement tiles. Dislocations, swelling (bulging) of partitions (light walls) and ceilings made of corrugated sheet, wooden panels.
0,15 - 0,25	Cracks, cracks (fragmentations) of concrete or stone walls, unreinforced, 20 - 30 cm thick
0,2 - 0,5	Ruptures of air reservoirs (hydrocarbons, etc.)
0,5 - 0,6	Bulging or brick walls destruction, unreinforced, 20-30 cm thick
0,7 - 1	Overturning of loaded wagons, destruction of reinforced concrete walls . Blowing (throwing) brick walls

Table 1.2. Dynamic effects of an explosion on humans

Overpressure in the shock wave front, (bar)	Effect
0,2 - 0,3	Mild trauma (contusions, ringing of the ears)
0,3 - 0,5	Medium trauma (contusions, deafness)

0,5 - 1,0	Severe trauma (fractures, internal bleeding)
1,0	Very serious trauma, practically incompatible with life
4,0 - 6,0	Certain death

The existence of the danger of accidental initiation / detonation, respectively the establishment of causes and possibilities that can generate the initiation / detonation of pyrotechnic devices, is achieved for each equipment depending on the elements of the structure of the technological process.

The organizational aspects of explosion protection must be adapted to the technical problems specific to each workplace so that no weak points arise in explosion protection installations.

The concept of assessing the effects produced following the triggering of pyrotechnic articles for automotive use is a sequential process that involves, both quantitative assessment of risk estimation based on available data and information (accident history and statistics, test and test results, technical and scientific information, safety sheets, technical product specifications, experience and technical expertise in the field of experts), as well as the qualitative assessment of risk assessment taking into account subjective aspects and perception of how specific effects manifest and generate, according to Table 1.3.

Table 1.3. Risk assessment matrix

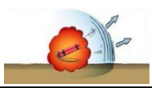
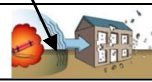
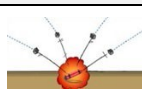
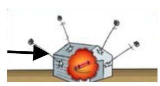
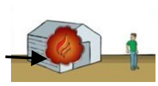
Risk assessment				Probability classes, P					
			Severity classes, G		Frequently	Probable	Occasional	Rar	Improbable
	Qualitative	Example		Catastrophic	M	M	M	M	Me
				Criticism	M	M	M	Me	Mi
				Medium	M	Me	Me	Mi	Mi
				Negligible	Me	Mi	Mi	Mi	Mi
	Quantitative	Example	1 x 10^{-6} – estimation of the value of the annual probability of death, P_{death}						
Legend: M-high risk; Me-medium risk; Mi-little risk			➔ direction of reduction of risk parameters P and G						

Exposure of persons is a measure of the probability ($0 \le P \le 1$) that they are present at the time of the explosion event, expressed in number of hours per year (in case of exposure of one person), and in the case of several exposed persons the number of hours in a year multiplied by the number of these persons.

In Table 1.4. The main mechanisms of impairment by death or injury (major or minor), as well as by material destruction, following the occurrence of an explosion-type event when carrying out specific operations with explosive materials, are highlighted, which can be grouped as follows:

1. *Overpressure and momentum* (overpressure from the shock wave front);
2. *Structural response* (destruction of buildings and breaking of windows with the projection of resulting fragments);
3. *Debris* (fragments resulting from the detonation of explosive materials, from: explosive products - primary fragments; construction materials of spaces intended for operations with explosive materials - secondary fragments; pieces of rock from craters formed - auxiliary debris);
4. *Thermal radiation* (specific to explosive materials classified in division HD 1.3 - explosives causing mass arson).

Table 1.4. Highlighting the effects and consequences of the main mechanisms of impairment generated by the detonation of explosive materials

	Inside the space for operations with explosive materials	Between the explosives operation space and the office building	Near the office building	Inside the office building
Pressure and momentum				
Destruction of windows and building				
Debris-es				
Thermal radiation				

The effects and consequences of each mechanism of impairment, mentioned above, occur successively, respectively, the danger that generates an explosion-type event inside the space intended for operations with explosive materials, affects the structure of its building, which is located at a certain distance from the office building, and may also affect its structure, and consequently the human component present inside it.

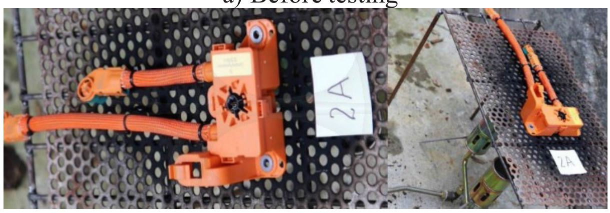
2 Performing specialized tests on pyrotechnic articles for automotive purposes in order to evaluate their behavior at their accidental initiation / triggering [5],[6],[7],[8]

2.1 Testing of pyrotechnic articles for automotive use by exposing them to high temperatures and open flame

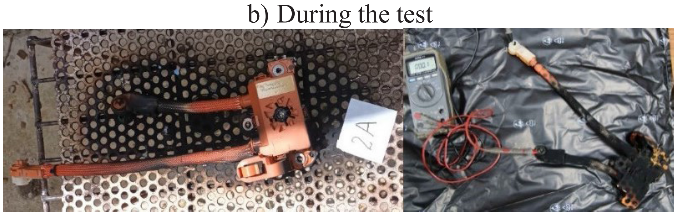
The testing of pyrotechnic articles for automotive purposes by exposing them to high temperatures (open flame) was carried out in order to determine their behavior following direct exposure to fire. For this purpose, the technical testing infrastructure consisted of the configuration of a fire dynamometer consisting of a gas cylinder containing propane gas, connection hose, double gas burner with a diameter of 60 mm, steel metal support and an expanded metal grid provided with holes for uniform distribution of heat flow, generated by the flame of fire, along the entire length of the tested product. Following exposure to open flame, for 30 minutes, traces of thermal effects were found, whose intensity was gradually manifested during this time interval, affecting first the insertion materials in the connecting cables, and then of the product casing, which showed traces of smoking / burning / melting.

In the case of pyrotechnic articles for automotive use, the initiation of related pyrotechnic compositions has not been found. Both before and after the end of the open flame exposure test of pyrotechnic articles for automotive use, the continuity of the circuit was measured using the ESCORT 179 Multimeter measuring device, finding that exposure to flame did not interrupt the circuit due to failure to initiate the incorporated pyrotechnic articles.

a) Before testing



b) During the test



c) After testing

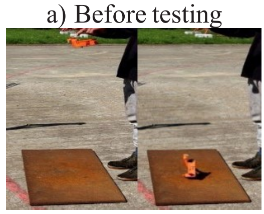
Fig. 1. High temperature and open flame testing of pyrotechnic articles for automotive use

2.2 Carrying out the fall test on pyrotechnic articles intended for automotive use

The purpose of this test was to determine whether pyrotechnic articles for automotive use have any negative effect following free fall from a specified height, thus simulating their behavior when accidentally falling on the ground, respectively whether the impact with the impactor surface triggers the initiation/triggering of the pyrotechnic composition related to the pyrotechnic articles within them.

Both before and after the end of the fall test of pyrotechnic articles for automotive use, the continuity of the circuit was measured using the ESCORT 179 Multimeter measuring device, finding that the impact generated by hitting the contact area with the fall surface did not cause the initiation of the incorporated pyrotechnic articles and consequently the non-interruption of the circuit.

a) Before testing



b) During the test

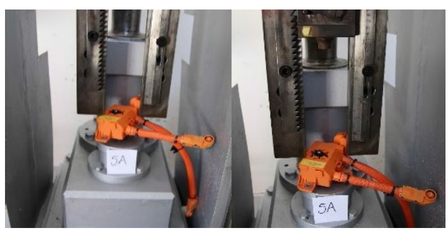
Fig. 2. Drop test on pyrotechnic articles for automotive use

2.3 Testing of pyrotechnic articles for automotive use against mechanical shock

The testing of the two assemblies provided with one or two pyrotechnic articles as well as the discardable product component by exposing them to an external stimulus of mechanical shock type was carried out using the specialized Sonnet stand provided by the specialized laboratory, ensuring a predetermined impact energy by means of a striking load with a mass of 5 kg allowed to fall freely from a height of 1 meter, ensuring an impact energy with value of 50 joules.

This test was performed in order to determine the behavior of these samples following the accidental fall of bodies of different masses on their surface in the area of arrangement of pyrotechnic articles, finding their non-initiation / non-triggering due to the damping of the impact of the impact of the weight with the sample casing and consequently maintaining the continuity of the circuit (failure to initiate the pyrotechnic composition).

a) Before testing



b) During the test

c) After testing

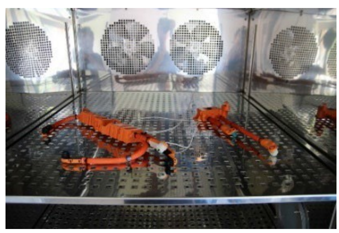
Fig. 3. Testing of pyrotechnic articles for automotive use against mechanical shock

2.4 Performing the test on thermal and mechanical conditioning (vibration exposure) of pyrotechnic articles for automotive use

2.4.1 Thermal conditioning test for pyrotechnic articles for automotive use

The purpose of this test was to determine the ability of the tested samples (pyrotechnic articles for automotive use) to withstand temperature conditions characterized by different heating and cooling regimes, thus simulating their behavior following their exposure to thermal variations corresponding to different working conditions/environments and/or storage. This test was performed using a specialized Climate Chamber equipment, equipped with built-in software for configuring different pre-established thermal conditioning cycles according to the specifications of the applicable referential (ISO 14451:2013). Both before and after the end of the test on thermal conditioning of pyrotechnic articles for automotive use, the continuity of the circuit was measured using the ESCORT 179 Multimeter measuring device, finding that exposure to an external stimulus such as a temperature variation did not cause the initiation / triggering of the incorporated pyrotechnic articles and consequently the non-interruption of the circuit. The duration of a predetermined thermal conditioning cycle was 24 hours.

a) Before testing



b) During the test

Fig. 4. Thermal conditioning testing of pyrotechnic articles for automotive use

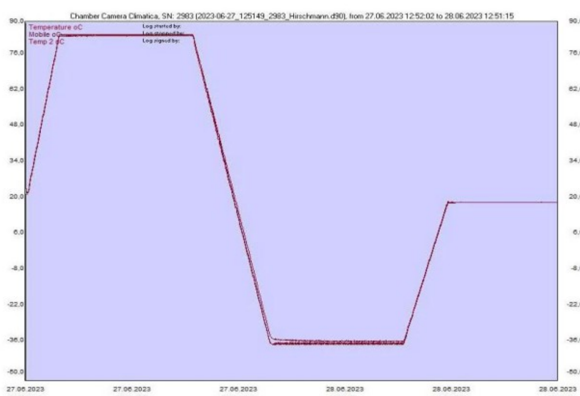
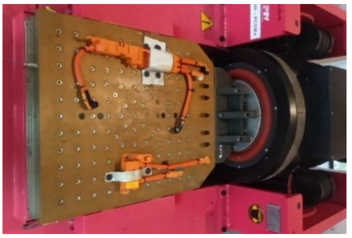


Fig. 5. Graphic on thermal conditioning of pyrotechnic articles for automotive use

2.4.2 Performance of the test on mechanical conditioning (exposure to vibration) of pyrotechnic articles for automotive use

The purpose of this test was to determine the ability of the tested samples to withstand different regimes of mechanical stress by exposure to axial mechanical vibrations. The duration of a predetermined mechanical conditioning cycle was 24 hours for each of the OX and OY axes. Both before and after the end of the test regarding the mechanical conditioning of pyrotechnic articles for automotive use, the continuity of the circuit was measured using the ESCORT 179 Multimeter meter, finding that exposure to an external stimulus such as mechanical vibration did not cause the initiation / triggering of the incorporated pyrotechnic articles and consequently the non-interruption of the circuit.



a) Before testing

b) After testing

Fig. 6. Mechanical conditioning testing of pyrotechnic articles for automotive use on the X-axis

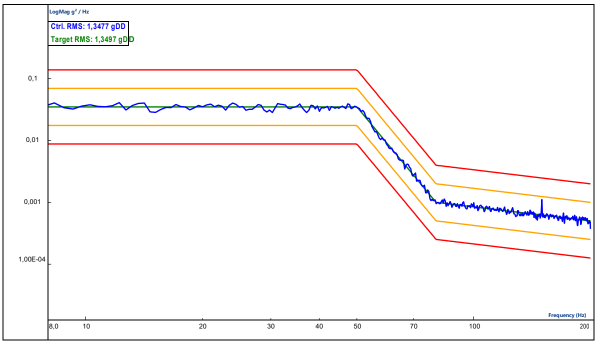
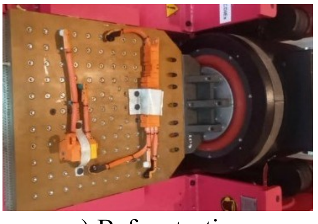
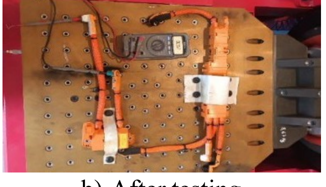


Fig. 7. Graph on mechanical conditioning of pyrotechnic articles for automotive use on the X-axis



a) Before testing



b) After testing

Fig. 8. Mechanical conditioning testing of automotive pyrotechnic articles on the Y-axis

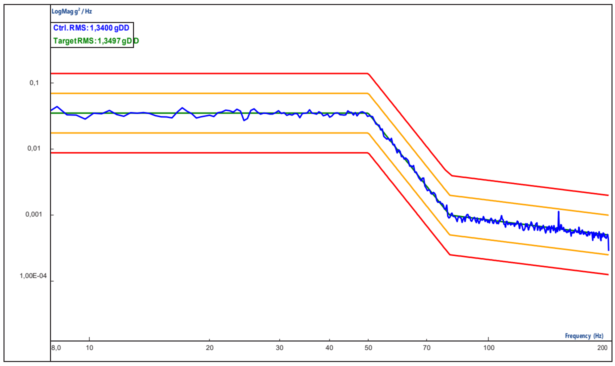
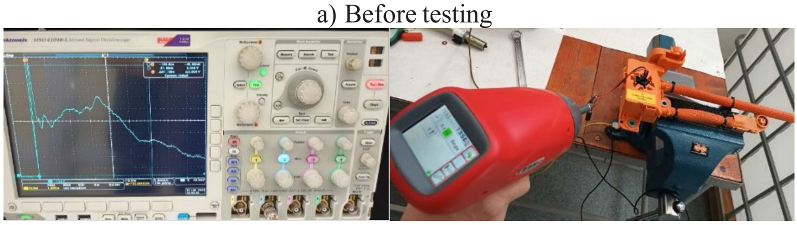


Fig. 9. Graph on mechanical conditioning of pyrotechnic articles for automotive use on the Y-axis

2.5 Electrostatic charge testing of pyrotechnic articles for automotive use

The purpose of testing the tested samples (pyrotechnic articles for automotive use) was to demonstrate their ability to withstand electrostatic discharges without their uncommanded or untimely initiation.

a) Before testing



b) After testing

Fig. 10. Electrostatic discharge testing on pyrotechnic articles intended for automotive use

3 Conclusions

The object of assessing the effects produced following the triggering of pyrotechnic articles for automotive purposes that can lead to the accidental initiation of semi-finished products containing pyrotechnic articles in the process of handling / use / storage / transport, is represented by the estimation and assessment of the risk of initiation / detonation of pyrotechnic devices, classified in category P1, based on the quantification of hazards specific to operations with these types of products, carried out in various phases of the technological flow, used in the manufacture of subassemblies for interrupting the electrical circuit in motor vehicles.

The role of the actuator is to interrupt the electrical circuit in which it is serialized, if a vehicle is involved in an accident, an electrical signal is generated in the circuit that initiates the pyrotechnic device.

Safety protection against detonation due to accidental initiation is of particular interest for safety because these detonations endanger the life and health of workers as a result of the uncontrollable effects of deflagration and pressure, the presence of toxic reaction products and the consumption of oxygen in ambient air which workers must breathe. At the same time, it should be borne in mind that material losses caused by explosions can be especially high.

The existence of the danger of accidental initiation / detonation, respectively the establishment of causes and possibilities that can generate the initiation / detonation of pyrotechnic devices, is achieved for each equipment depending on the elements of the structure of the technological process.

The organizational aspects of explosion protection must be adapted to the technical problems specific to each workplace so that no weak points arise in explosion protection installations. The risk assessment at accidental initiation / detonation of semi-finished products containing pyrotechnic devices was carried out considering the technical factors of their exposure to dangerous external stimuli (stray currents, electrical discharge, high temperature, impact) thus favoring the occurrence of undesirable events, it is recommended to safely perform specialized experimental tests on similar products using a technical testing infrastructure appropriate.

The main specialized tests performed on pyrotechnic articles for automotive use focused mainly on their exposure to dangerous external stimuli: high temperatures (higher than 165 ^{o} C) and/or open flame, mechanical shock, mechanical vibrations, impact blows, electrostatic charge (electrical discharge greater than 25 KV), currents with intensity greater than 0.4 A in order to evaluate their behavior at their untimely initiation/triggering, respectively:

- Testing pyrotechnic articles for automotive purposes by exposing them to high temperatures and open flame;
- Performing the fall test on pyrotechnic articles for automotive purposes;
- Testing pyrotechnic articles for automotive use at mechanical shock;
- Performing the test on thermal and mechanical conditioning (vibration exposure) of pyrotechnic articles for automotive use;
- Electrostatic charge testing of pyrotechnic articles for automotive use;

Acknowledgements

This work was carried out through the ”Nucleu” Program within the National Plan for Research, Development, and Innovation 2022-2027, with the support of the Romanian Ministry of Research, Innovation and Digitalization, project no. 23 32 02 03, title: *Development of monitoring methods to reduce environmental impact from the use of explosive materials, pyrotechnic articles, and application of blasting technologies*.

References

1. Law 126/1995 on the regime of explosive materials, with subsequent amendments and completions.
2. "Technical Norms – to Law 126/1995 – regarding the possession, preparation, experimentation, destruction, transport and storage, handling and use of explosive materials in any other specific operations in the holders' activities, as well as the authorization of fireworks and pyrotechnicians", with subsequent amendments and completions.
3. DECISION no. 536 of 30 May 2002 approving the Technical Norms regarding the possession, preparation, experimentation, destruction, transport, storage, handling, and use of explosive materials used in any other specific operations in the holders' activities, as well as the authorization of fireworks and pyrotechnicians.
4. DECISION no. 1102 of 10 December 2014 laying down the conditions for making pyrotechnic articles available on the market.
5. Law 319/2006 on occupational safety and health.
6. Methodological Norms – dated 11.10.2006 – for the application of the provisions of the Law on Safety and Health at Work nr. 319/2006.
7. GD 197/2016 on establishing requirements for making available on the market and control of explosives for civil use.
8. Guide to good practice for storage, transport, and use of explosive materials.