DEVELOPMENT OF TESTING INFRASTRUCTURE FOR MARITIME PYROTECHNIC ARTICLES

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Abstract: Advances in safety science and occupational risk management for industrial applications using explosive materials require a robust testing infrastructure. This paper aims to develop a comprehensive framework for the testing of maritime pyrotechnic articles, addressing regulatory requirements, infrastructure design and implementation. The study is based on International Maritime Organisation (IMO) and European Union guidelines, ensuring compliance with rigorous safety standards. The methodology involves detailed calibration and validation of test equipment such as climate chambers, digital gauges and timers to measure critical parameters such as ignition delay, burn time and operational efficiency under extreme conditions. Hand flares and floating smoke flares are subjected to extensive cyclic temperature, immersion and operational stress testing to verify durability and performance. Findings demonstrate that proper conditioning and testing of marine pyrotechnic products in controlled environments can significantly enhance their reliability and safety. The study concludes that a well-structured testing protocol, aligned with international safety standards, is essential to minimise risk and ensure high levels of operational safety in maritime applications.

Keywords: Maritime Pyrotechnics, Safety Science, Occupational Risk Management, Testing Infrastructure, Explosive Materials, IMO Standards, Calibration and Validation, Burn Time, Ignition Delay, Temperature Cycles

1. INTRODUCTION

The current challenges in the testing of maritime pyrotechnic articles are significant due to the stringent safety standards required by international regulatory bodies. This paper aims to address these challenges by developing a comprehensive testing infrastructure that meets the requirements of the IMO and EU directives. The

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objective is to ensure that maritime pyrotechnic devices, such as hand flares and buoyant smoke signals, are thoroughly tested under extreme conditions to guarantee their reliability and safety.

The products to be tested by INSEMEX - (LMEAP) include marine distress signals and rescue products such as hand flares and buoyant smoke signals. The testing of the products will be conducted according to a test program based on IMO MSC.1/Circ. 1629, IMO MSC.48 (66), and IMO MSC.81 (70), but in a reduced format.

The testing will focus on the most safety-critical tests, specifically: measuring dimensions and mass, temperature cycling test, low temperature conditioning, high temperature conditioning, 1-meter immersion for 24 hours, safety inspection, operation at ambient temperature, operation at conditioning temperature, operational test using immersion suit gloves, burning time of flare, flare immersion test underwater, and the heptane test.

2. TESTING INFRASTRUCTURE

2.1 Test Equipment and Materials

In this study, the following equipment and materials were specifically used for the testing of maritime pyrotechnic articles: Climate chamber ARALAB Type TESTA CT 1000 ECP 45, BINDER climate chamber type ED 720, Laboratory freezer FROSTER 520, Balance PARTNER type PS 4500/C/2, Digital Caliper KLASS, Digital Chronometer HANHART DELTA E 200, IBC container, Glass vessels, Stainless steel vessels, Small refrigerator, Small heater, and a maritime suit.

2.2 Testing Procedure

Data collection and analysis were conducted using LMEAP - 16 testing procedure, based on IMO.MSC.81(70), IMO MSC.1/Circ.1629, and IMO MSC.48(66). The test procedures involved thermal cycling, immersion tests, and operational tests of hand flares and buoyant smoke signals.[3, 12, 19, 20]

Although the Laboratory for Explosive Materials and Pyrotechnic Articles meets the requirements of SREN ISO-IEC 17025:2005 and is accredited by RENAR, it can only conduct accredited testing for pyrotechnic articles intended for entertainment, professional use, and stage and theater purposes. It is not accredited for testing marine pyrotechnic articles [1, 2, 3, 10, 12].

In light of this situation, the laboratory members meticulously examined the applicable standards and directive. They carefully evaluated the necessary equipment for the specific tests and identified any additional stands or equipment that need to be acquired or constructed to successfully conduct these tests.

Available equipment for testing:

- Climate chamber ARALAB, Type TESTA CT 1000 ECP 45, measurement range: 45 °C ÷ 180 ˚C; 10 ÷ 98 % rH., inside dimensions: L x l x H = 105 x 99 x 107 (figure 1);

– BINDER climate chamber, type ED 720, measurement range: 5°C ÷ 300 ˚C, inside dimensions: L x l x H = 100 x 60 x 120 (figure 2);

Fig.1. Equipment for temperature cycling test / Low temperature conditioning / High temperature conditioning

Fig.2. Equipment for temperature cycling test / High temperature conditioning

– Laboratory freezer FROSTER 520, measurement range: - 5°C - 35 °C, inside dimensions: L x l x H = 60 x 42 x 140 (figure 3);
– Balance PARTNER type PS 4500/C/2, Series No.254113/09, measurement range: max 4500 g and Digital Caliper, KLASS: Serial no. 31C628, measurement range: 300 mm (figure 4);

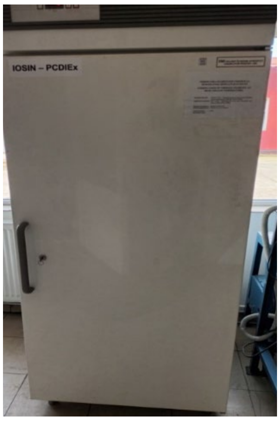

Fig.3. Equipment for temperature cycling test / Low temperature conditioning

Fig.4. Equipment's for measuring dimension and mass

– Digital Chronometer, HANHART, DELTA E 200, Serial No. M231271, measurement range: 9h59 min:59,99 sec. (figure 5);
– IBC container, inside dimensions: L x l x H = 110 x 90 x 92 (figure 6);

Fig.5. Equipment for measuring Burning time of flare / test functioning

Fig.6. Vessel for the 24-hour immersion test

Equipment/materials that have been acquired for testing:

- Glass vessels, inside dimensions: L x l x H = 35 x 40 x 80 and 100 x 40 x 50 (figure 7);
- Stainless steel vessels having in the middle a removable support of 1.2 m height , inside dimensions: L x l x H = 100 x 100 x 20 (figure 8);

Fig.7. Glass vessel for flare immersion test under water

Fig.8. Stainless steel vessel for Heptane test / Functioning test

- Small refrigerator, inside dimensions: L x l x H = 45 x 28 x 37 (figure 9)

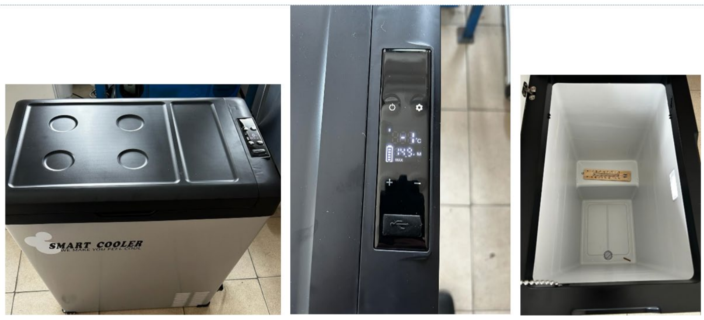

Fig. 9. Equipment for Low temperature conditioning test

- Small heater, inside dimensions: L x l x H = 45 x 28 x 37 (figure 10)

Fig.10. Equipment for High temperature conditioning test

- A maritime suit made of reinforced neoprene, featuring a face seal and flapmade of reinforced neoprene and incorporates a face seal and flap, 2 or 3 fingered gloves, front waterproof zipper, ankle cuffs, neoprene pocket and retro-reflective tape (figure 11);

Fig.11. Operator in insulated buoyant immersion suit / Operational test using immersion suit gloves

Data collection and analysis are fundamental processes in research and decision-making. Accurate data collection methods and rigorous analysis techniques ensure the reliability and validity of findings, providing a solid foundation for informed decisions. To achieve this, marine distress signals and rescue products, such as hand flares and buoyant smoke signals (figure 13), were acquired and subjected to various tests and experiments. Hand flares: a short-range distress signal used to pinpoint position, with length: 235mm, exterior diameter: 29mm and mass: 190g (figure 12);

Fig.12. Hand flares distress signal used to pinpoint position

Fig.13. Buoyant smoke signal, smoke/aerosol generator

Buoyant smoke signal: is a Smoke/Aerosol generator, which when activated emits smoke of a highly visible colour for a period of not less than 3 min when floating in clam water, height: 115mm, exterior diameter: 75mm and mass: 390g (figure 13);

Based on the results and applicable standards, the testing procedure was developed. To facilitate these tests, the LMEAP testing procedure was specifically developed and implemented LMEAP - 16 which is based on IMO.MSC.81(70), IMO MSC.1/Circ.1629, and IMO MSC.48(66).

3. RESULTS AND DISCUSSION

The thermal cycling tests demonstrated that all specimens passed visual inspections and functional tests, with no signs of damage. The immersion tests showed that while the visual inspection confirmed no physical damage, two specimens failed to ignite after immersion, highlighting areas for reliability improvement. The heptane test revealed that two specimens ignited the heptane, indicating a need for improved ignition safety mechanisms.

3.1. Performance under cycling Temperature Testing

<table>
<tr><td>Hand flares</td><td>Manufacturer: ALBATROSS S.r.L., Napoli - ITALIA
Model: HAND FLARE II – JA-12
Lot/Serial Number: 32284, 32285, 32286</td><td colspan="3">Date: 01.02.2024 ÷ 26.02.2024 Time:
Surveyor: Jitea Ciprian
Organization: INCD-INSEMEX PETROSANI</td></tr>
<tr><td colspan="2">3.2.2 Temperature cycling test</td><td colspan="3">Regulations: LSA Code I/1.2 & III/3.2; MSC.81(70) 1/1.2.1 & 4.2.1</td></tr>
<tr><td>Test Procedure</td><td>Acceptance Criteria</td><td colspan="3">Significant Test Data</td></tr>
<tr><td rowspan="8">The three specimens of hand flares should be alternately subjected to surrounding temperatures of -30°C and +65°C. These alternating cycles need not follow immediately after each other and the following procedure, repeated for a total of 10 cycles, s acceptable:</td><td rowspan="8">After the test, each specimen should show no sign of damage such as shrinking, cracking, swelling, dissolution or change of mechanical qualities and should then function at ambient temperature.

The three flares should burn for a period of not less than1 minute.</td><td>1</td><td>2</td><td>3</td></tr>
<tr><td colspan="3">Condition (Pass/Fail)</td></tr>
<tr><td>Pass</td><td>Pass</td><td>Pass</td></tr>
<tr><td colspan="3">Burn time (sec)</td></tr>
<tr><td>66</td><td>67</td><td>68</td></tr>
<tr><td colspan="3">Time delay (if applicable) (sec)</td></tr>
<tr><td>2.46</td><td>2.68</td><td>2.59</td></tr>
<tr><td colspan="3" rowspan="5">Comments/Observations:

<u>PASSED</u></td></tr>
<tr><td>.1 an 8 h exposure at a minimum temperature of +65°C to be completed in one day;</td><td>The hand flare should not cause discomfort to the person holding the casing and not endanger the survival craft by burning or glowing residues when used in accordance with the manufacturer's operating instructions.</td></tr>
<tr><td>.2 the specimens removed from the warm chamber that same day and left exposed under ordinary room conditions at a temperature of 20°C ± 3°C until the next day;</td><td rowspan="3"></td></tr>
<tr><td>.3 an 8 h exposure at a maximum temperature of -30°C to be completed the next day; and</td></tr>
<tr><td>.4 the specimen removed from the cold chamber that same day and left exposed under ordinary room conditions at a temperature of 20°C ± 3°C until the next day.
The three hand flares after completing temperature cycling should function effectively at ambient temperature.</td></tr>
</table>

Fig.14. Hand Flare temperature cycling test results

The thermal cycling test was performed on nine specimens of smoke signals, alternating between temperatures of -30°C and +65°C. The test consisted of ten cycles, each involving an 8-hour exposure at +65°C followed by room temperature stabilization, and an 8-hour exposure at -30°C with similar stabilization. The results demonstrated that all specimens passed the visual inspection and functional tests, exhibiting no signs of damage such as shrinking, cracking, swelling, or changes in mechanical properties. Furthermore, the specimens operated effectively at ambient temperature after the cycling, with all units burning uniformly and meeting the required operational standards (figure 14) [4, 5, 6, 11, 13, 15].

3.2. Immersion Testing Outcomes

Following the regulations, the flares were immersed horizontally under 1 meter of water for 24 hours. Post-test examination required each specimen to exhibit no signs of damage such as shrinking, cracking, swelling, dissolution, or changes in mechanical qualities, and to function effectively at ambient temperature [7, 8, 9, 14, 17, 18].

The results were as follows (figure 15): all three specimens passed the visual inspection; burn time: Specimen 14 burned for 74 seconds; burn times for specimens 13 and 15 were not applicable; time delay: 2.61 seconds for specimen 13, 2.36 seconds for specimen 14, and 2.31 seconds for specimen 15; However, it was observed that specimens 13 and 15 did not function after initiation.

Hand flares	Manufacturer: ALBATROSS S.r.L., Napoli - ITALIA Model: HAND FLARE II – JA-12 Lot/Serial Number: 32287 (13), 32288 (14), 32289(15)/ -	Date:26.02.2024 Time:10 ÷13 Surveyor: Jitea Ciprian Organization: INCD-INSEMEX PETROSANI		
3.2.6.1 1 metre immersion for 24 hours test		**Regulations: LSA Code I/1.2 & III/3.2; MSC.81(70) 1/4.3.1**		
Test Procedure	Acceptance Criteria	Significant Test Data		
		13	**14**	**15**
Three specimens of hand flares should be immersed horizontally for 24 h under 1 m of water.	After the test, each specimen should show no sign of damage such as shrinking, cracking, swelling, dissolution or change of mechanical qualities and should then function at ambient temperature.	Condition (Pass/Fail)		
		Pass	Pass	Pass
		Burn time (sec)		
		-	74	-
		Time delay (if applicable) (sec)		
		2.61	2.36	2.31
	The three flares should burn for a period of not less than 1 minute.	Comments/Observations: **- Specimens 13 and 15 did not functioned after initiation**		
	The hand flare should not cause discomfort to the person holding the casing and not endanger the survival craft by burning or glowing residues when used in accordance with the manufacturer's operating instructions.			
		Failed		

Fig.15. Hand Flare 1 meter immersion for 24 hours test

The hand flares are designed to not cause discomfort to the person holding the casing and to not endanger the survival craft by burning or glowing residues when used according to the manufacturer's operating instructions.

3.3. Heptane test

Each hand flare was activated at a height of 1.2 meters above a 1-meter square test pan containing 2 liters of heptane floating on a layer of water, conducted at an ambient temperature of +20°C to +25°C. The flares were required to burn completely without igniting the heptane, and to burn for a period of not less than 1 minute.

The results were as follows (figure 16): heptane ignition, specimens 16 and 17 failed the test by igniting the heptane (figure 17) while the specimen 18 did not function after initiation; burn time: 66 seconds for specimen 16, 65 seconds for specimen 17, and specimen 18 did not function after initiation; time delay: 2.05 seconds for specimens 16 and 18, and 2.21 seconds for specimen 17.

<table>
<tr><td>Hand flares</td><td colspan="2">Manufacturer: ALBATROSS S.r.L., Napoli - ITALIA
Model: HAND FLARE II – JA-12
Lot/Serial Number: 27393(16), 27391(17), 27397(18) / -</td><td colspan="3">Date:26.02.2024 Time:10 ÷13
Surveyor: Jitea Ciprian
Organization: INCD-INSEMEX PETROSANI</td></tr>
<tr><td colspan="2">3.2.8 Heptane test</td><td colspan="4">Regulations: LSA Code I/1.2 & III/3.2; MSC.81(70) 1/4.7.3</td></tr>
<tr><td colspan="2">Test Procedure</td><td>Acceptance Criteria</td><td colspan="3">Significant Test Data</td></tr>
<tr><td colspan="2" rowspan="8">Three hand flares should be activated at 1.2 m above a test pan 1 m squarecontaining 2 litres of heptane floating on a layer of water. The test should be conducted at an ambient temperature of +20°C to +25°C. The flare should be allowed to burn completely.</td><td rowspan="8">The three specimens should not ignite the heptane. The flare should burn for a period of not less than 1 minute.

The hand flare should not cause discomfort to the person holding the casing and not endanger the survival craft by burning or glowing residues when used in accordance with the manufacturer's operating instructions.</td><td>16</td><td>17</td><td>18</td></tr>
<tr><td colspan="3">Heptane ignition (Pass/Fail)</td></tr>
<tr><td>Fail</td><td>Fail</td><td>-</td></tr>
<tr><td colspan="3">Burn time (sec)</td></tr>
<tr><td>66</td><td>65</td><td>-</td></tr>
<tr><td colspan="3">Time delay (if applicable) (sec)</td></tr>
<tr><td>2.05</td><td>2.21</td><td>2.05</td></tr>
<tr><td colspan="3">Comments/Observations:

Specimen 18 did not functioned after initiation

Failed</td></tr>
</table>

Fig.16. Hand Flare Heptane test

Fig.17. Hand flare igniting the heptane

5. CONCLUSIONS

This study successfully developed a comprehensive testing infrastructure for maritime pyrotechnic articles. However, to enhance reliability, future research should address the failure modes observed, comparing the findings with recent studies in the field. Continuous improvements and adherence to international standards are important for minimizing risks and ensuring the safety of maritime operations. The thermal cycling test subjected smoke signals to alternating temperatures of -30°C and +65°C over ten cycles. All specimens passed visual inspections and functional tests, showing no signs of damage such as shrinking, cracking, swelling, or changes in mechanical properties. The specimens maintained operational efficiency at ambient temperature, burning uniformly and meeting the required standards. In the 1-meter immersion test, three hand flare specimens were immersed in 1 meter of water for 24 hours. Post-immersion, the flares needed to show no physical damage and function effectively at ambient temperature. While the visual inspection confirmed no damage, two specimens (13 and 15) failed to ignite. However, specimen 14 successfully burned for 74 seconds with acceptable time delays, indicating areas for improvement in reliability.

The heptane ignition test involved activating the flares at a height of 1.2 meters above a pan containing heptane. The results showed that two specimens (16 and 17) ignited the heptane, failing the test, while specimen 18 did not function. The burn times for specimens 16 and 17 were 66 and 65 seconds respectively, highlighting the need for improved ignition safety mechanisms to prevent unintended ignition of flammable substances. Overall, the study underscores the importance of stringent testing protocols for ensuring the safety and reliability of maritime pyrotechnic articles. The current testing infrastructure at INSEMEX - LMEAP is robust and capable of simulating extreme conditions, but continuous enhancements and adherence to international standards are important to minimize risks and ensure high operational safety in maritime applications. Future efforts should address the failure modes observed during the tests to further enhance the reliability of these critical safety devices.

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