TECHNICAL NOTE

FLAME SPREAD AND SMOKE & TOXICITY TESTING INTERPRETATIONS FOR PLASTIC PIPES

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SUMMARY

Lightweight composite materials are increasingly used in the ship industry as a substitute to their heavier steel alternatives. These materials are often inherently flammable and require an assessment of the fire risk associated with their flame spread and smoke & toxicity in order to enable their safe usage. However, for plastic pipes there are contradictions within the IMO (International Maritime Organisation) guidelines which lead to different interpretations and different implementations. The goal of this work is to evaluate whether smoke and toxicity is adequately assessed for products currently approved for use and commercially available on the market. Testing according to standardised means given in the IMO code shows that the materials fail both flame spread and smoke & toxicity testing. This proves that there are different interpretations and illustrates the need for clarity in this area to enable safe and consistent use of these materials.

NOMENCLATURE

CFE	Critical heat flux for extinguishment (kW m^{-2})
Q_p	Peak heat release (kW)
Q_{sb}''	Minimum heat for sustained burning (kW m^{-2})
Q_t	Total heat release (kW)
ASTM	American Society for Testing and Materials
FED	Fractional Effective Dose
FP	Fire Protection
FR	Flame retardant
FTP	Fire Test Procedures
GFRP	Glass Fibre Reinforced Polymer
IACS	International Association of Classification Societies
IMO	International Maritime Organisation
LIFT	Lateral Ignition and Flame spread Test
MSC	Maritime Safety Committee
NC	Nanofiller
SDC	Ship Design and Construction
SOLAS	Safety of Life at Sea

1. INTRODUCTION

A number of considerations are important for materials in the maritime sector which requires a balancing act to achieve the optimal choice. Weight reduction represents an attractive option since it can directly reduce the cost associated with materials, and also allows greater shipping loads without increased material usage. Originally wood was the material of choice for ships before eventually changing to steel due to its greater strength and its non-combustible nature. Most recently composite polymers have been used which represent high-strength lightweight alternatives to steel. Additionally, their usage as pipes is beneficial due to their corrosion resistance. However, these materials are often inherently combustible and thus require an alternate design path for their inclusion in ships. Some concern has been raised regarding the potential smoke and toxicity of modern products used on ships but as of yet this has not yet been proven. Under the IMO guidelines – which are covered in more detail in the following sections – it is necessary to test materials for flame spread and smoke & toxicity. Some exceptions exist for materials with low flame spread, and there are also some differing interpretations of the guidelines due to some inconsistencies. It is therefore necessary to first assess whether there is any potential smoke and toxicity risk associated with lightweight plastic pipes.

The goal of this work is to assess whether materials with poor smoke and toxicity performance according to the standard IMO code are currently used in practice. This will be achieved by performing standardised testing of materials with low flame spread which have exemption from these requirements. Additionally, a review of the relevant routes to approval and existing approval certificates are studied, and a short literature review into the relationship of flame spread and smoke & toxicity for flame retardant materials is performed.

2. MARITIME REGULATIONS

The design of ships and marine structures is given by the *"International Code for the Application of Fire Test Procedures (FTP)"* (IMO 2010a), which is mandatory under Chapter II-2 of the Safety of Life at Sea (SOLAS) convention, 1974. The FTP code contains parts for surface flammability test (part 5) which includes the LIFT (Lateral Ignition and Flame Spread Test, ISO 5658-2) apparatus, and also smoke and toxicity (part 2), based on the smoke density chamber test (ISO 5659-2).

2.1 HISTORICAL DEVELOPMENT

The IMO (International Maritime Organisation) Resolution A.753(18) '*Guidelines for the application of plastic pipes in ships*' (IMO 1993) was adopted in 1993 and sets requirements for flame spread of plastic pipes fitted on board high speed craft within accommodation spaces and other areas, specifically service and control spaces. The main objective by IMO was to take a more proactive approach when implementing measures to address trends of developments in the marine industry which might adversely affect the safety of ships. This proactive approach was an IMO policy agreed in the 1990s following major fatalities caused by fire casualties, most notably the '*Scandinavian Star*'.

The guideline was developed due to the increased use of plastic pipes in ships in place of metallic piping, with a particular focus on flame spread and smoke & toxicity due to the increased fire load introduced by these materials. At the time of preparing the guidelines, test procedures were available for flame spread but not yet developed for smoke and toxicity. Resolution MSC 41(64) (IMO 1994, Maritime Safety Committee) therefore set interim standards for measuring smoke and toxic products of combustion, where plastic piping was specifically referenced in the Resolution under the section '*Test specimen'*. The interim Resolution was further discussed at FP (Fire Protection) Sub-Committee, and agreed not to be developed further. Several other papers at FP-40 aimed at developing the interim Resolution changed the compounds identified and modifying critical levels to be considered and forming the basis for the test in FTP Code Part 2. To correlate test criteria in the FTP Code Part 2, with the lacking test procedures in the Guidelines, a reference was included in the FTP Code (IMO 2010a) under instructions for preparation of specimens and classification criteria for plastic piping in *'Fire test procedures for smoke generation'.*

2.2 CURRENT USE

The latest changes to the Guidelines (IMO 1993) were introduced at MSC 95 following the IMO SDC_2, that is, the second session of the Sub-Committee on ship design and construction, and adopted in Resolution MSC 399(95) (IMO 2015). The Guidelines clearly referenced the 2010 FTP Code for flame spread and smoke and toxicity and a new procedure modification set out in Appendix 3 to include curvilinear pipe surfaces, which had been missing previously. One notably change was also the exemption from smoke and toxicity testing if the flame spread testing showed compliance with the total heat release (Q_t) and peak heat release rate (Q_p) as in 2010 FTP Code Annex 2, paragraph 2.2. The aim of this was to bring smoke and toxicity testing in line with exemption for exposed interior surfaces.

The aforementioned Resolutions are directly referenced or include references to plastic pipes. The exception of this is the MSC.1/Circ. 1120 '*Unified Interpretations of SOLAS Chapter II-2, the FSS Code, the FTP Code and related fire test procedures*' (IMO 2004), which is a further inclusion of the MSC/Circ. 965, adopted by MSC 72 following FP44 Sub-Committee of fire protection. This relaxes flame spread and smoke & toxicity testing for plastic pipes within accommodation spaces, service spaces and control stations. The contradictions between MSC.1/Circ. 1120 and the Guidelines have led to inconsistencies in the requirements for plastic pipes in ships, with some Administrations requiring full compliance with the flame spread and smoke & toxicity requirements of the FTP Code through applications of SOLAS Chapter II-2/5.3.2.4 and II-2/6.2, whilst others have no requirements. To rectify the situation there have been attempts to make the Guideline a mandatory instrument but so far without success.

2.3 FUTURE APPLICATION

The inconsistencies in applying MSC.1/Circ. 1120 and the Guidelines have, despite the continued development, not resulted in a coherent approach by Administrations and have not been widely implemented. IACS (International Association of Classification Societies) has developed P4 '*Production and Application of Plastic Pipes on Ships*', latest revision is rev. 4 of Dec. 2008. This is identical to the Guidelines however it does not include the latest MSC Resolutions but is expected to be revised soon through the IACS safety panel.

3. FLAME RETARDANTS AND TOXICITY

The exemption from smoke and toxicity (IMO 2010b) is implicitly based on the concept that for traditional materials there is no issue if the flame spread is low. However, many contemporary products achieve low flame spread due to the inclusion of fire retardants. Existing literature, as detailed below, has shown that the addition of fire retardants can increase the toxicity of a material in some cases. This would then necessitate the need for performing smoke and toxicity testing for low flame spread products to verify their safety.

The literature shows that an increase in the yield of toxic gases is adequate to represent sufficient hazard, despite a decrease in ignitability and flame spread. This has been true for polymers in well ventilated conditions, where both brominated and halogenated FR (flame retardants) have been shown to bring the FED to potentially fatal levels (Molyneux, Stec and Hull, 2014). For various plastics it was also noted that there was a reduction in the lethal concentration due to the addition of FR (Levin, 1987). For polymers containing NC (nanofillers) or FR there was an increase in the CO yield in well ventilated conditions, but no change in under ventilated conditions (Stec and Rhodes, 2011). These results all highlight the need to assess toxicity independently of flame spread. Adeosun (2014) identified the toxic compounds produced by various FR foams, in agreement with Paabo and Levin (1987) and Woolley *et al.* (1975). The findings demonstrated that a wide range of toxic products were possible for a variety of FRs. Levin (1987) also found that FR additives were highly toxic in some specific configurations. Thus, there is sufficient evidence to suggest that materials containing flame retardants have the possibility of representing a greater toxic hazard. These materials should therefore be tested for toxicity independently of their flame spread classification.

4. TESTING

Testing has been performed according to the standardised procedures given in the FTP code (IMO 2010a), parts 2 (smoke and toxicity) and part 5 (flame spread). A total of six plastic pipes were tested for flame spread, all of which are commercially available and approved for use on board ships. Two of these pipes were GFRP (glass fibre reinforced polymer) and were further tested for smoke generation and toxicity. These were selected based on the results from the flame spread testing.

4.1 FLAME SPREAD

All the pipes tested failed the flame spread criteria for bulkhead, wall and ceiling linings given by IMO. The results are given in Table 1. Pipes A and B, the GFRP pipes, failed on the critical heat flux for extinguishment, *CFE*, the total heat release, Q_t, and the peak heat release Q_p. In order to pass, these should be greater than or equal to 20.0 kW m^{-2} for CFE, less than or equal to 0.7 MJ for Q_t, and less than or equal to 4.0 for Q_p. The flame spread for Pipes C and D was excessive to the point that the tests had to be aborted, and thus the products are considered to have failed and the values given are not representative. Pipes E and F had the best flame spread performance out of the six pipes tested but still failed on the requirement for Q_t.

4.2 SMOKE GENERATION AND TOXICITY

The purpose of the project was to evaluate smoke and toxicity of materials with low flame spread. However, as noted in the previous section, none of the commercially available products were capable of passing the flame spread test and thus could not be considered to have low flame spread. Nonetheless, two of the pipes were chosen to continue on to the smoke generation and toxicity test. These two pipes were selected based on the hypothesis that they might perform the best out of the six plastic pipes.

Table 1: Flame spread results for the six plastic pipes, labelled A-F. Values in italics indicate the material has exceeded IMO guidelines.

	A	**B**	**C[1]**	**D[1]**	**E**	**F**
CFE (kW·m^{-2})	*9.00*	*9.47*	13.25	9.31	23.90	30.78
Q_{sb}'' (MJ·m^{-2})	5.73	4.61	3.47	2.35	7.82	33.35
Q_t (MJ)	*4.54*	*5.49*	5.38	2.81	*1.67*	*2.17*
Q_p (kW)	*5.37*	*5.26*	21.94	13.71	2.55	1.75
Burning droplets	No	No	Yes	Yes	No	No

[1] Test was aborted due to excessive flame spread.

Table 2: Smoke generation and toxicity results averaged from three tests. Gas concentrations are given in ppm, and irradiance in kW m-2. Values in italics indicate the material has exceeded IMO guidelines.

	Pipe A			**Pipe B**		
Irradiance	50	25	25*	50	25	25*
Smoke generation						
D_m	*>1320*	215	*458*	*>1320*	145	*692*
Toxicity						
CO	375	93	131	518	64	242
HCl	2	0	0	2	2	0
HF	1	0	0	0	0	0
NO_x	192	27	112	211	22	152
HBr	0	0	0	0	0	0
HCN	9	14	1	17	0	4
SO_2	0	11	0	0	5	0

* With pilot flame

Both of the pipes tested, A and B, failed on the requirement for smoke generation (Table 2). The products did however pass for all criteria on toxicity, but nevertheless still do not comply with the IMO guidelines. The failure to pass part 2 illustrates that it is possible that materials with high smoke generation and toxicity can be used on board ships but not because they have low flame spread. It is thus evident that there must be another way of approving these products for them to be used.

The IMO part 2 test uses the NBS Smoke Chamber apparatus which exposes 75 by 75 mm samples to a thermal irradiance in a sealed box to represent under-ventilated conditions. Smoke generation is checked against specific optical density requirements depending on the type of product, and toxicity concentration must be below set levels for a number of key compounds. Samples are tested at 50 kW m^{-2} and 25 kWm^{-2} unpiloted, and then a further test at 25 kW m^{-2} with a pilot flame, each with a minimum of three repetitions. The NBS smoke density chamber has been criticised in the past for its ability to evaluate under-ventilated conditions (Stec and Hull, 2011) but it is nonetheless chosen in this case since it is a part of the IMO guidelines.

5. TYPE APPROVAL REVIEW

A review of type approval certificates was performed in order to understand which methods were used to approve plastic pipes and to quantity the number which pass or do not pass flame spread and smoke & toxicity requirements as given in IMO. Neither the full certificates nor the approval procedure are typically publicly available and so the number of documents reviewed was limited and may not be representative of the whole area.

There were three out of twenty-eight type approvals which were tested and approved according to the FTP code part 5 for flame spread. A further twenty instead used an alternate flame spread test. This was the ASTM D635 standard, entitled '*Standard Test Method for the Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position*'. This is not referenced in IMO, and the connection between this test and the flame spread part 5 is not available in the literature. Finally, the last five type approvals had no flame spread testing listed.

For smoke and toxicity only two of the twenty-eight were tested according to FTP Code part 2, and the remaining twenty-six had no testing listed. This illustrates that there is the potential for a significant number of products on the market to have poor smoke and toxicity performance compared to the IMO guidelines. A lack of transparency in type approvals means that it is difficult to ascertain for anyone outside whether or not there may be an issue.

6. CONCLUSIONS

The conclusions of this work are as follows:

- There are contradictory statements in the IMO codes which lead to confusion for the treatment of plastic pipes on ships. There needs to be clarity of these to ensure consistent and transparent implementation across different administrations.
- In some cases it has been shown that the inclusion of flame retardants can increase or otherwise not reduce the smoke & toxicity. This suggests that it may be necessary to properly assess materials even if they have low flame spread.
- Commercially available plastic pipes approved for use in most of the cases studied do not pass the smoke & toxicity requirements given in IMO.
- Finally, the flame spread approved for use is assessed in a different way than that given by IMO. Of the products that were tested in this project, all failed IMO part 5.

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