Harmonization and Improvements to Fast Heating Test Procedures – IMEMG Proposals

IMEMG FCO Working Group

Presenter: Marie De Bats

www.imemg.org

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INTRODUCTION

- IMEMG

21 company groups from 7 countries:

INTRODUCTION

- CONTEXT

  - <u>Fast Heating objective</u>
    - Hazard classification with respect to large liquid fuel fire

  - <u>STANAG 4240</u>
    - Applied in most of tests centres

  - <u>Future changes</u>
    - International push to develop/institute alternative fire
    - Some test centre already investigating alternative fire tests, *BUT no standard*

No confidence at the beginning and now new AOP in preparation…

- IMEMG Fast Heating Working Group - Goals :

  - Harmonize Fast Heating test procedures and acceptance criteria
    - Identify key test methodology criteria in STANAG 4240
    - Compare test facilities in Europe (DE, FR, NO, SE, SP, UK) : fuel types, temperature, item position, mounting, sensors, wind barrier
  - Look for new alternative solutions
    - Reduce environmental problems due to the burning of liquid fuels (smoke, lead, soil pollution)
    - Save costs : test cost + avoid test duplication due to different methods from different countries
  - Evaluate equivalence of liquid fuel and alternative solutions
    - Compare test methods and results : temperatures, heat fluxes, etc.
    - Propose calibration criteria and method for Fast Heating tests

STANDARD FIRE TEST

- Main objectives (STANAG 4240 ed.2):
  - ✓ Testing in a **realistic configuration** (item packaging / configuration & position / support …)
  - ✓ Ensuring **correct heating** of test item, corresponding to a hot LFF (hydrocarbon) :
    - Rapid & full engulfment
    - Appropriate temperatures and fire duration
  - ✓ Getting **relevant evidence** (measurements) → reaction level & time assessment of tested item

Liquid Fuel Fire
(Courtesy of SBTC, Sweden)

- Other recommandation:
  - ✓ **Test repeatability** is required → for comparison between tests (≠ objects and / test centers)

STANDARD FIRE TEST

- Standard Fire Test – analysis and comments :

  ✓ **Heating conditions** : test repeatability and uniformity difficult to ensure

  - **Fire-to-fire dispersion** → average flame temperatures [800 - 1100°C]
  - **Spatial dispersion within a single fire** → typically +/- 100°C

  ✓ **Wind** identified as critical test parameter / one of the most difficult constraint in FH testing :

  - T°C ➚ : wind can activate combustion (bringing O2 to flame)
  - T°C ➘ : potential emergence of item from flame envelope

  => Improvement necessary (wind screen efficiency / compatibility with fragments mapping for reaction assessment)

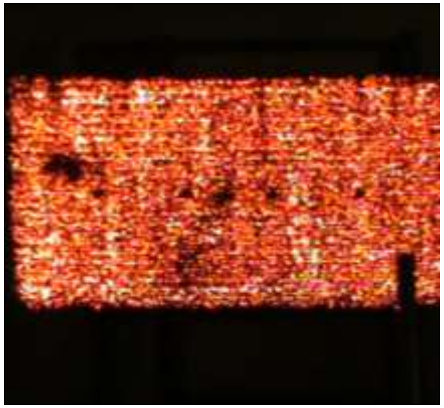
  ✓ STANAG not adapted for munitions with short reaction times (<30s)

Alternative Fire Test

- General idea

  - Replace kerosene by less polluting fuels
  - LPG burners, propane jets, sand-bed burners, radiant panels, etc.
    - Very different alternative test setups experimented throughout the world
    - Large or small scale facilities

LPG Fire
(Courtesy of WTD91, Germany)



Radiant panel
(Courtesy of Herakles, France)

Propylene gas burners
(Courtesy of Nexter, France)

A challenge

→ Consistency of IM results shall be guaranteed whatever the fire test method

And an opportunity

→ To get a better control of fire heating parameters (lower spatial dispersion, better repeatability)

SFT/AFT comparison

- Flame temperature cannot be the only metric
  - ➢ What about heat fluxes ?

	SFT	AFT
Flame characteristic	Buoyant, turbulent diffusion flame	Turbulent diffusion or pre-mixed flame
Flame temperature [°C]	[600-1100°C]	[xxx-1200°C]
Heat transfers	Mainly radiative [soot] Low influence of item external surface emissivity due to pollution by soot	Depending on test setup: • Incident and absorbed radiative HF • Convective exchanges depending on burners position, flow rates, etc.
HF values	10kW/m²-400kW/m² [1]	127-136kW/m² Propane [1]

- **Target value of 80 - 150kW/m²** seems to be globally acknowledged
- **How to ensure similar IM signature ?**
  - Flame temperature and total heat load received by the test item
  - Spatial heat flux distribution
  - Impact of predominant heat transfer mode ?

[1] IMEMTS 2013, T16003_Yagla
Experimental development of propane burners for fast cook off testing

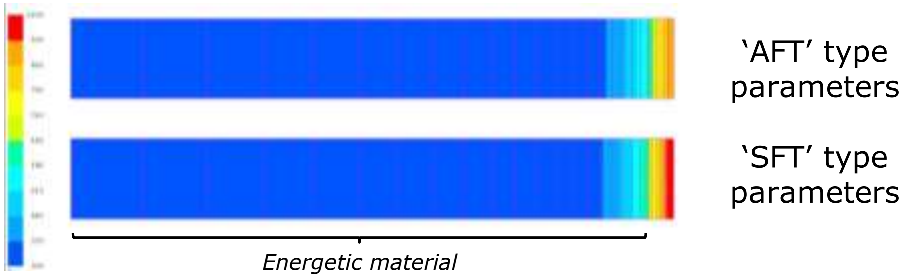
SFT/AFT comparison

- Rough sensitivity study

<u>Objective</u>: to compare reaction times and case temperatures at reaction for fires with similar global heat fluxes but different exchange parameters

- Cylindrical test object
  - ϕ 150mm
    Steel Case 1,5mm
    Heat Shield 5mm
    Energetic material

- Finite Element model (axi)



- Energetic material reaction:

$T_{ignition}=500K$

- Wall heat flux approximated by:

$$\varphi = h.(T_f - T_w) + \varepsilon_w.(\varepsilon_f.\sigma.T_f^{\,4} - \sigma.T_w^{\,4})$$

Range (1):
[76-202] kW/m²

(1) peak value with Twall=300K

SFT/AFT comparison

- Rough sensitivity study

  - Parameters range

$$\varphi = h.(T_f - T_w) + \varepsilon_w.(\varepsilon_f.\sigma.T_f{}^4 - \sigma.T_w{}^4)$$

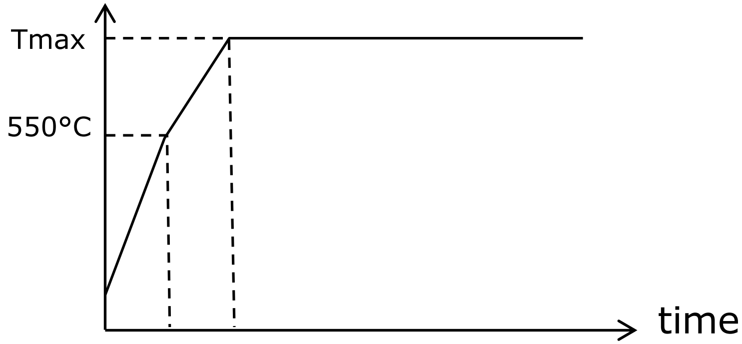
Heating parameters

Parameter	Value
TF MAX [°C]	[800-1100]
HF [kW/m²]	[76-202]

Parameter	"SFT"	"AFT"
ε_f [-]	[0.9-1]	[0.3-0.5]
ε_w [-]	0.9	0.5
h [W/m²K]	20	*Calculated such as HF_AFT=HF_SFT*

TF profile

Parameter	Value
time 550°C [s]	5s
time TF_MAX [s]	15s



SFT/AFT comparison

- Rough sensitivity study
  - Reaction time results

Case	A	B	C	*D*	
STANAG (1) reaction time [s]	HF 76kW/m² (TF max 800°C)	**HF 83kW/m² (TF max 800°C)**	**HF 184kW/m² (TF max 1100°C)**	HF 202kW/m² (TF max 1100°C)	**Delta B-C**
SFT	147s	**131s**	**82s**	76s	49s
AFT (ε=0,5)	175s	**167s**	**93s**	90s	74s
AFT (ε=0,3)	185s	-	97s	-	
Delta SFT – AFT (ε=0,5)	28s	36s	11s	14s	

(1) STANAG reaction time = reaction time – time to reach 550°C

- Effect of fire heat flux : significant dispersion of reaction times in both cases
- Comparison "SFT"/"AFT" (similar HF level): higher reaction times with less radiative fires (all the more as flame temperatures are low)

SFT/AFT comparison

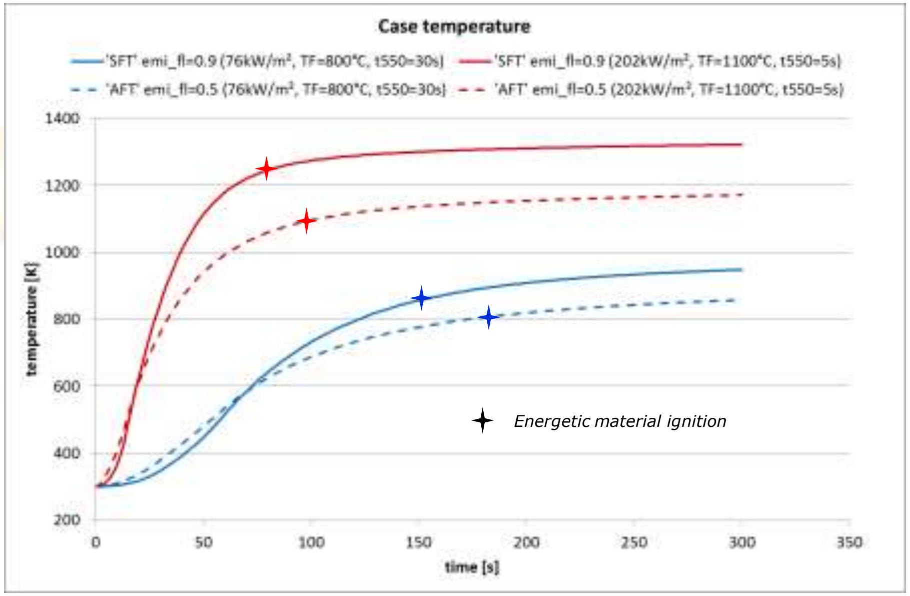
- Rough sensitivity study
  - Case temperature results: link with reaction violence

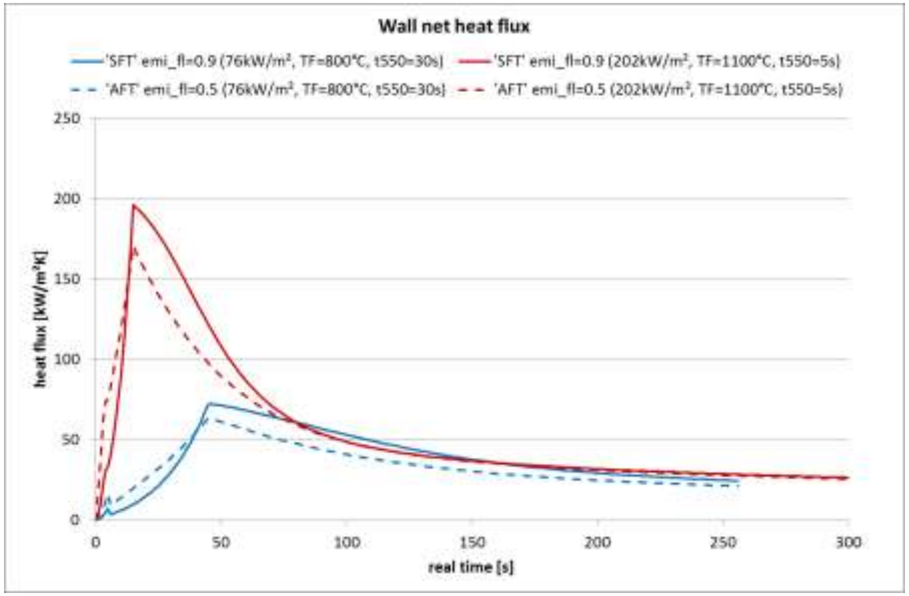
Case	A	B	C	D	
Case temperature at reaction [°C]	HF 76kW/m² (TF max 800°C)	**HF 83kW/m² (TF max 800°C)**	**HF 184kW/m² (TF max 1100°C)**	HF 202kW/m² (TF max 1100°C)	**Delta B-C**
SFT	620	**659**	**918**	974	259°C
AFT (ε=0,5)	548	**559**	**801**	815	242°C
AFT (ε=0,3)	529	-	767	-	
Delta SFT – AFT (ε=0,5)	72°C	100°C	117°C	159°C	

- Effect of fire heat flux : significant dispersion of case temperatures in both cases
- Comparison "SFT"/"AFT" (similar HF level): lower case temperatures with less radiative fires (all the more as flame temperatures are high)

SFT/AFT comparison

- Rough sensitivity study
  - Synthesis
    - Reaction time & temperature case dispersion
      - Function of heat flux history, flame temperature, convective/radiative ratio, emissivities, …





- Rough analysis… but highlights some difficulties with FH analysis
- Behavior probably different for smaller objects

SFT/AFT comparison

- Fire Tests equivalence

➢ LFF=real threat // AFT=equivalent approach

  - Comparable HF data achieved on some tests
  - Dispersion observed in both cases (fire-to-fire and spatial dispersion)

➢ Reaction may occur before steady state conditions are reached, thus:

  - Equivalence needs to be validated for all phases (ignition and hot phases)
  - Importance of radiative inputs (radiation > convection in buoyant flames)

=> Acceptance criteria = f(TF, HF and heat transfer mode)

FH calibration

- TEST CALIBRATION

BASE DEVICE REQUIREMENTS

ROBUST | CHEAP | EASY TO SOURCE

EASY TO USE | HARMONIZED

=> Simple object

TYPE OF MEASUREMENTS

FLAME TEMPERATURE

HEAT FLUX
NET ABSORBED/INCIDENT

CONVECTIVE/RADIATIVE RATIO

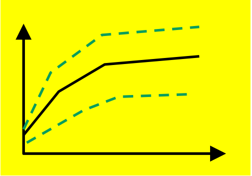
TIME-DEPENDENT
(FROM T0)

SPATIAL FIELD

=> Combination of thermocouples and calorimeter object

CRITERIA

UPPER BOUNDARIES | LOWER BOUNDARIES



- Coaxial thermocouples
- Sandia Hemispheric Heat Flux Gages (HFG)
- Differential Flame Thermometer (DFT)
- Calorimeters
- Directional Slug Calorimeter (DSC)
- Plate Thermometer (PT)
- Adiabatic Surface Temperature (AST) Probe
- ARL Container
- Two paired thermocouples
- Transverse Seebeck coefficient heat flux gage
- …

FH procedures – IMEMG proposals

- CONCLUSION
  - STANAG 4240 ed.2
    - Test repeatability and uniformity difficult to ensure
    - Wind control needs to be improved
  - Alternative fire tests
    - Cost reduction is unclear at the moment (function of size, inert/live, setup)
    - Opportunity to get a better control on fire parameters/dispersion
  - AFT calibration process = key point
    - Harmonized calibration device compulsory to obtain comparable measurements

Live test with gas burners
(Courtesy of Hirtenberger, Austria)

The consistency of IM test results shall be guaranteed whatever the fire test method

Live tests comparison is essential to increase confidence (from small ammunition to large rocket motors)

THANK-YOU FOR YOUR ATTENTION

IMEMG FCO GROUP

Eroan BENADE	TDA Armements SAS, France	*eroan.benade@tda.thalesgroup.com*
Gianluca BERSANO	Oto Melara, Italy	*Gianluca.Bersano@otomelara.it*
Marie DE BATS	MBDA, France	*marie.de-bats@mbda-systems.com*
Karl EDWARDS	BAE Systems – Munitions, UK	*karl.edwards@baesystems.com*
Martin EMSENHUBER	Hirtenberger Defence Systems, Austria	*M.Emsenhuber@hirtenberger.at*
Gerhard HUBRICHT	Rheinmetall Waffe-Munitions GmbH, Germany	*Gerhard.Hubricht@rheinmetall.com*
Peter JACOB	Bayern-Chemie GmbH, Germany	*Peter.Jacob@mbda-systems.de*
Volker KOMANSCHEK	TDW GmbH, Germany	*volker.komanschek@mbda-systems.de*
Christian MAURER	DIEHL BGT Defence, Germany	*christian.maurer@diehl-bgt-defence.de*
Caroline NGUYEN	Herakles, SAFRAN Group, France	*caroline.nguyen@herakles.com*
Frédéric SAULNIER	NEXTER Munitions, France	*f.saulnier@nexter-group.fr*
Konrad SCHMID	TDW GmbH, Germany	*konrad.schmid@mbda-systems.de*
Alexander ZINELL	Junghans Microtec GmbH, Germany	*alexander.zinell@junghans-microtec.de*