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Supporting Munitions Safety

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MSIAC WORKSHOP 2020

DEFECTS – CAUSES, CLASSIFICATION AND CRITICALITY

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ABSTRACT

Defects in energetic materials or in other materials used in munitions systems are often a cause for concern. This includes voids, cracks, and foreign materials, as well as chemical, physical and or mechanical properties that are outside design tolerance specifications. Defects in energetic materials are common and can have a significant impact on the safety and reliability of the munition, yet guidance and understanding on how to assess and sentence defects is often limited.

MSIAC are hosting a workshop intended to bring together stakeholders including munition designers, safety authorities and test personnel to develop a methodology by which we can approach the problem of defects. This will include the way in which we draw upon various sources of information to inform decisions with respect to the criticality of defects and the sentencing of munitions. The workshop will seek to achieve the following goals:

- Develop an understanding of the causes of defects with respect to different munition systems and designs, energetic materials, service environments and manufacturing processes, and attempt to predict their occurrence

- Develop an understanding of the detection methods for defects, including discussion of emerging technology

- Understand the effects of defects, including how they change the properties of energetic materials and ultimately safety, reliability and performance

- Discuss acceptance criteria based on the point at which defects impact safety, reliability and performance.

This paper presents how MSIAC plans to achieve these goals. MSIAC seeks the support of the community to provide feedback on proposals, aid in the preparation of the workshop, and finally to participate in the workshop in June 2020.

Keywords:

Defects, Defects Lexicon, Defects Taxonomy, Defect Detection

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ABBREVIATIONS

CASG	CNAD Ammunition Safety Group
CLC	Capability Life Cycle
LCEP	Life Cycle Environmental Profile
S3	Safety and Suitability for Service
TTCP	The Technical Cooperation Program

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INTRODUCTION

BACKGROUND

Defects in munition systems are common and can have a significant impact on Safety and Suitability for Service (S3). In the worst case, munition system defects can lead to catastrophic failure of the munition system with the potential to cause death or serious injury, and damage to platforms or systems with an associated loss of capability.

Figure 1: The in-bore detonation of a 155mm artillery round killed two Singaporean soldiers during a training exercise in New Zealand in 1997. The cause of the accident was determined to be a defective fuze. [1]

Despite these potentially serious consequences, guidance and understanding on how to approach, evaluate and assess the significance of defects is limited. This is exacerbated by the use of inconsistent terminology across the community in naming or describing defects. There is therefore a need to develop a methodology by which we can ultimately inform decisions with respect to the criticality of defects and the sentencing of defective munition systems. This need has been confirmed through various technical questions received by MSIAC from the international community.

This issue will be addressed through the MSIAC workshop titled *"Defects – Causes, Classification and Criticality"* which will take place in The Hague, The Netherlands from the 15th to the 19th of June 2020. This workshop will bring together stakeholders from a diverse range of backgrounds, including those working in destructive and non-destructive testing, materials science and engineering, munitions design, and application of safety policy in a national context, amongst others.

GOAL

The goal of the workshop is to define the methodology by which the criticality of the materials factors leading to failure of munition systems can be assessed, and how this assessment can then be used to inform safety and capability related decisions.

In order to achieve this goal, the workshop will seek to develop an understanding of the following:

- The types of structural defects and property changes which might occur in different types of munition systems (e.g. based on energetic material, role, service environment, age etc.) and the processes which leads to their creation and growth

- Techniques for the detection and characterisation of structural defects and property changes, including their limitations

- The impact of structural defects and property changes on Safety and Suitability for Service (S3) for different munition systems, energetic materials, roles and service environments

- The information that is required to support the decision making process, including tools that can be used to develop risk based arguments and the risk controls that can be implemented at various points in the Capability Life Cycle (CLC)

PRELIMINARY ACTIVITIES

To support the achievement of this goal, MSIAC staff will prepare technical reports to help underpin the discussion, ensuring that nations have a common understanding. To date we have undertaken the following preliminary activities:

- The development of a general model for the classification of the materials factors leading to failure of munitions systems, including definitions (discussed in Section 1)
- Collation and classification of known munition system defects, and development of a defects lexicon and taxonomy (discussed in Section 2)
- The review of techniques for the detection and characterisation of defects. [2]

MSIAC staff will continue to develop supporting technical materials and one can expect publication of additional reports in the run up to the workshop.

Also relevant is the work of the NATO CNAD Ammunition Safety Group (CASG; AC/326) Sub Group A to develop a standardized approach to the evaluation of the safety of energetic materials to gun launch setback loading, particularly with respect to the tolerability of defects. This work has been supported by MSIAC and will be a useful example of how defects are dealt with for a specific system. [3] [4] [5]

1 WORKSHOP STRUCTURE

1.1 OVERVIEW

The Defects Workshop will take place in The Hague, The Netherlands from the 15th to the 19th of June 2020, and will progress through a number of Plenary Sessions and parallel Focus Areas. At present, it is proposed that the workshop proceed as follows:

- Day 1: An opening plenary session to discuss the goals of the workshop, provide a baseline understanding of the theories and tools supporting the workshop, and to introduce the various Focus Areas. Presentations will be made by both MSIAC staff and delegates.

- Day 2/3/4: Four parallel Focus Areas, each sitting for three sessions. After each session a group briefing session will be held to present the outputs of each Focus Area.

- Day 5: A closing plenary session to discuss the workshop conclusions, and propose a way forward for future work.

This proposed workshop structure is presented below in Figure 2.

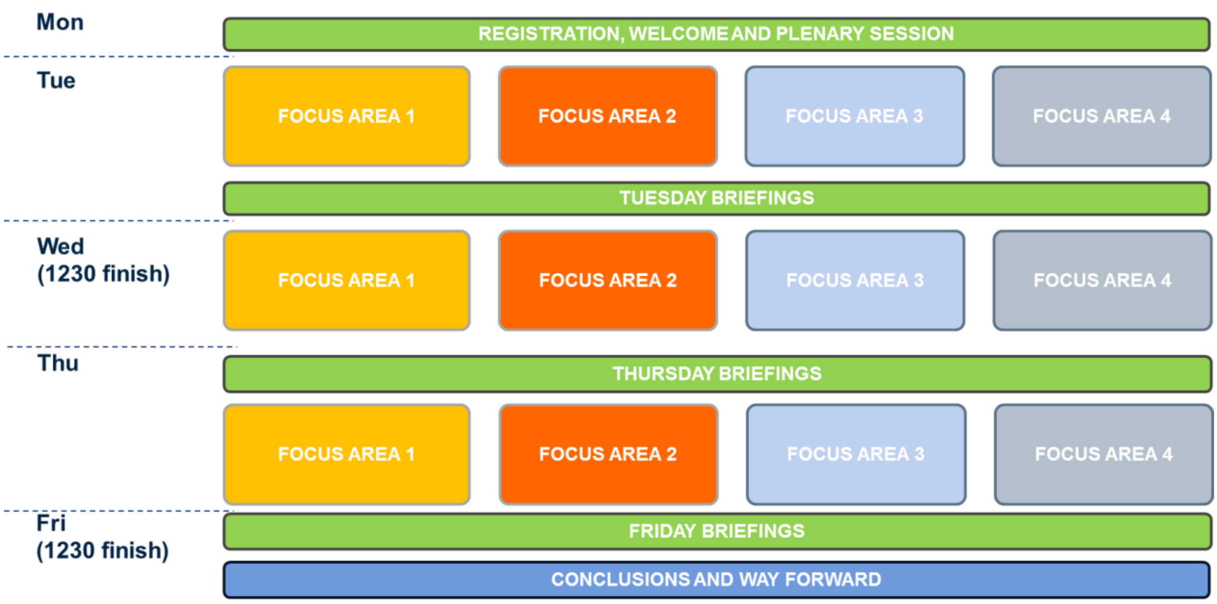

Figure 2: Proposed structure of the MSIAC Defects Workshop

The individual Focus Areas, including proposed topics of discussion and expected outputs, are discussed in the following paragraphs. These focus areas may potentially be further sub-divided to consider specific technology areas where munition system design or application necessitates a different approach (e.g. warheads / rocket motors / gun launched munitions etc.).

1.1.1 Focus Area 1: Origin of Defects

The first Focus Area will consider the types of structural defects and property changes which might be experienced in different types of munition systems (e.g. based on energetic material, role, expected LCEP, age etc.) and the processes which leads to their creation and growth. This will include:

- Identification of typical defects for different categories of munition system / designs / energetic materials / service environments / manufacturing processes / inert materials etc.

- Determination of how defects are created, grow and change, and how this might be modelled

OUTPUTS: guidance on the types of defects to look for in certain types of munition systems and energetic materials, and at what point in the CLC they may be expected to occur.

1.1.2 Focus Area 2: Detection of Defects

The second Focus Area will consider the techniques which might be employed for the detection and characterisation of structural defects and property changes, including their limitations. This will include:

- Identification of best practice detection techniques for different defects or property changes, or for different munition system types. This will include consideration of both destructive and non-destructive methods.

- Emerging technology for the detection of defects and property changes

- Limitations in current techniques (both technological and human factors) and capability gaps

- Calibration of detection techniques, including the replication of defects for this purpose (feasibility, reproducibility, representativeness)

OUTPUTS: guidance on best practice techniques for detection of particular types of defects, and applicability of these techniques to different munition systems.

1.1.3 Focus Area 3: Consequences of Defects

The third Focus Area will consider the impact of structural defects and property changes on S3 for different munition systems, energetic materials, roles and service environments. This will include:

- Identification of the safety hazards associated with defects and property changes, based on energetic materials, munition system type, role, expected LCEP, age etc., and a ranking of their importance on this basis

- Methods to quantify the extent of these hazards (e.g. qualification, GAP tests, small scale hazard tests etc.)

OUTPUTS: guidance on the energetic material and munition system hazards that exist for different defects, and how these may be quantified.

1.1.4 Focus Area 4: Criticality of Defects

The final Focus Area will consider the information that is required to support the decision making process, including tools that can be used to develop risk based arguments and the risk controls that can be implemented at various points in the CLC. This will include:

- Understanding the point at which defects impact S3, and the standardisation of acceptance criteria on this basis. This will include consideration of how the criticality of defects influences product specifications.

- Strategies for risk treatment (e.g. 100% radiography of a lot / batch and selection of best ones etc.)

- The role of statistical methods and other tools in quantitative risk assessment

OUTPUTS: guidance on the tools, techniques and evidence that can be used to assist in the decision making process at different points in the CLC, and the types of risk controls that may be employed.

1.2 MATERIALS SCIENCE AND ENGINEERING CONCEPTS

A number of concepts have been developed by the MSIAC staff which it is hoped will be useful in framing discussion during the workshop. This includes the following general model for classification of material performance.

In the field of material science and engineering, it is a well-established paradigm that there is a strong interrelationship between a material’s properties, composition and structure, synthesis and processing, and performance. The interrelationship between these factors is commonly represented as a tetrahedron (see Figure 3).

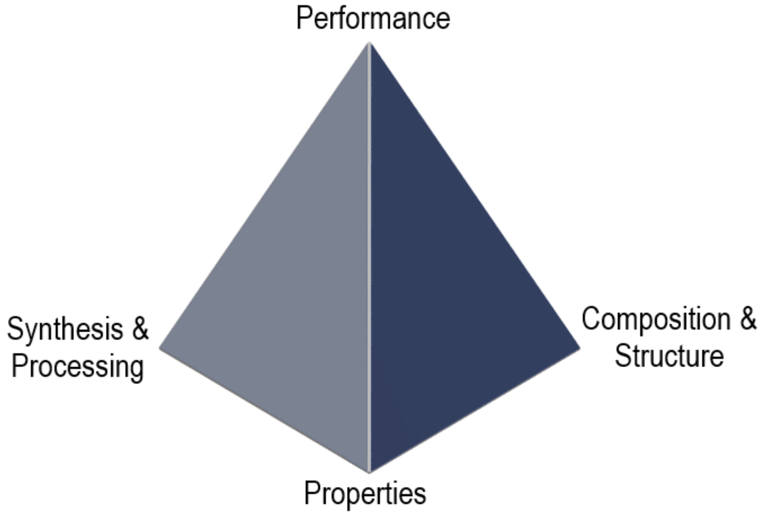

Figure 3: The interrelationship between a material's properties, structure and composition, synthesis and processing, and performance.

Based on this approach it is clear that the performance of a material in its intended application is highly dependent on the other three factors, noting that the performance of a material must always relate to some given application, for instance its ability to withstand some outside influence or force.

We can also consider how these same factors may lead to unacceptable performance or failure of a material. As before, the interrelationship between a material's properties, composition and structure, synthesis and processing, *and failure* can also be represented as a tetrahedron (Figure 4).

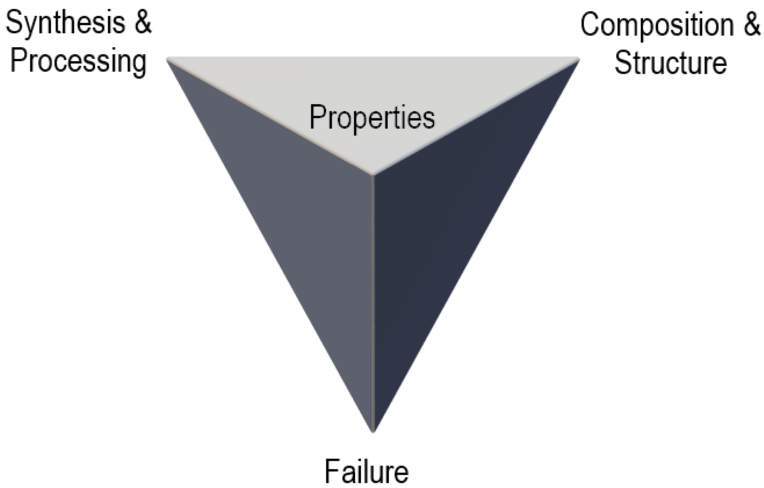

Figure 4: The interrelationship between a material's properties, structure and composition, synthesis and processing, and its potential for failure.

The logo for the workshop is based on an intersection of these two tetrahedrons, and represents a way in which we may consider a continuum of material performance based on the other three factors (Figure 5).

Figure 5: The logo for the MSIAC Defects Workshop, representing a continuum of performance based on a material's properties, structure and composition, and synthesis and processing.

Throughout the workshop, it is hoped that the materials science and engineering paradigm will provide insights into the appearance of and changes in defects. The identification and understanding of the interrelationships between the material factors of structure, processing, properties and performance will provide a fresh perspective to defects and their causes, characterization, and criticality.

This paradigm has also formed the basis for the structure of a defect lexicon and taxonomy, as discussed in the next section.

2 LEXICON AND TAXONOMY

2.1 BACKGROUND

There is a lack of clarity and consistency in the use of terminology for describing and classifying material failures in energetic materials and munition systems. For example:

- The terms “Cavity”, “Chasm” and “Void” may be used somewhat synonymously to describe an absence of material, but may also be used to differentiate between material absences of varying sizes, locations or causes.

- Terms are provided without definition, the implicit assumption being that the reader is familiar with the meaning. This can be a particular problem where different professional communities routinely use the same term to convey different concepts, potentially leading to misunderstandings.

- Where definitions are provided, they may be relative to another term or a dictionary definition, and often no attempt is made to characterise the defect by size, shape and/or volume.

Such inconsistencies can make communication difficult, particularly when attempting to describe causes, criticality and potential controls.

A technical question to support The Technical Cooperation Program (TTCP) Energetic Materials Defects Focus Area was received by MSIAC in the summer of 2017. The request asked MSIAC to engage the munitions community for help with defining a defect lexicon and taxonomy for rocket motors, warheads, bombs and gun-launched munitions, including the definition of defect criticality and inspection criteria. The scope of this request was subsequently extended to provide a review and comparison of all defect terms related to energetic materials and munitions, to be achieved through the establishment of an ongoing MSIAC Work Element.

This work forms the basis of a common language for discussion of energetic and munition system material failures, and is therefore a vital precursor to the planned MSIAC Defects Workshop.

2.2 LEXICON

Over a period of two years, MSIAC staff have gathered terms from the literature related to defects in energetic materials and munition systems, and compiled these into a lexicon. The aim of the lexicon is to propose a single, unambiguous definition for the most common defects and material failures.

Each term within the lexicon is accompanied by a definition and, wherever possible, illustrative images. In addition, each term is categorised in accordance with the following criteria:

- The family of energetic materials to which the described feature belongs (explosives, propellants and / or pyrotechnics)
- The size or observable scale of the feature (nm-µm, µm-cm, cm-m)
- The location of the feature (bulk, interface and / or surface)
- The time at which the feature would be introduced (processing, integration and / or ageing)

There are currently 148 terms in the lexicon, taken from 170 unique sources. It is planned to finalise and publish the lexicon prior to the Defects workshop in June 2020.

2.2.1 Survey

In order to give the munitions community an opportunity to contribute to the development of the lexicon, a survey has been uploaded to the MSIAC website. This survey provides the opportunity to comment on the proposed definitions of each term, propose alternate definitions, and upload and share relevant images.

All persons involved in the munitions industry are encouraged to contribute before the end of January 2020.[1]

2.3 TAXONOMY

During compilation of the lexicon, it became apparent that there was a need to classify the various terms in a manner that grouped like terms together, and that allowed a rapid appreciation of the nature of a given defect and those other defects to which it is most similar.

Through a trial and error approach, various iterations of the defect taxonomy were produced; a successful model was eventually found in the material science and engineering approach described in Section 1.

Each term in the lexicon is classified as being related to the synthesis and processing of a material; the composition and structure of a material; or the properties of a material. An example of this classification is shown below in Figure 6. As with the

[1] https://www.msiac.nato.int/defect-lexicon-questionnaire

lexicon, it is planned to finalise the taxonomy and publish it prior to the Defects workshop in June 2020.

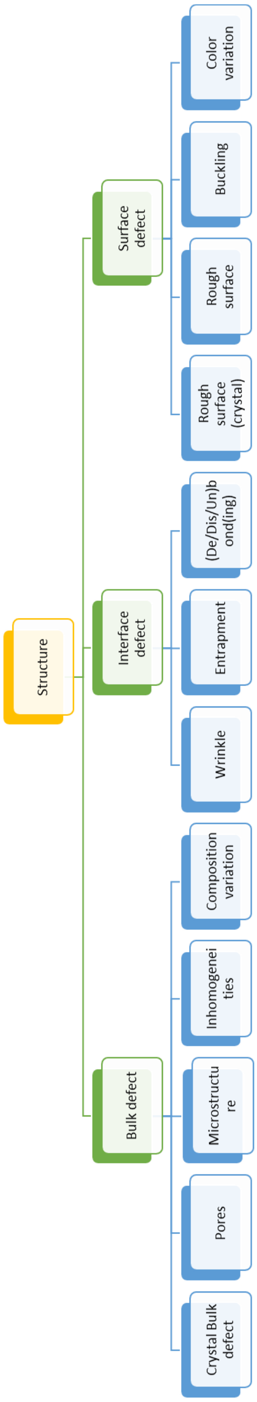

Figure 6: Taxonomy of defect terms related to the composition and structure of a material

CONCLUSIONS

In the real world, the condition of munitions is often found to deviate from the condition when initially qualified. The occurrence of defects inevitably leads to the need to make a decision on how much deviation constitutes a problem, whether that be safety, reliability, or performance related. This workshop offers an opportunity for the international community to come together and develop best practice on how we approach such decisions.

As always, the success of MSIAC's workshops relies on the engagement of the community, allowing us to gain input from as broad a range of perspectives as possible. To this end we wish to encourage stakeholders working in destructive and non-destructive testing, materials science and engineering, munitions design, and application of safety policy in a national context to participate.

To enable this diverse group to work together efficiently and achieve the goals of the workshop, MSIAC will continue its technical preparation work. So far, efforts have been directed at developing a common language through the defects lexicon and taxonomy, and a general model for classification of material failures.

We encourage those involved in the munitions industry to consider contributing to this effort, either through completing the defect lexicon survey, providing feedback on the proposals within this document, or by participating in the Defects Workshop scheduled to take place between the 15th and the 19th of June 2020.

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