INTERNATIONAL MARITIME ORGANIZATION

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SUB-COMMITTEE ON CARRIAGE OF CARGOES AND CONTAINERS
2nd session
Agenda item 5

CCC 2/INF.6
12 June 2015
ENGLISH ONLY

AMENDMENTS TO THE IMSBC CODE AND SUPPLEMENTS

Information supporting the proposed inclusion of a new test in appendix 2 and inclusion of Screening Criteria based on Particle Size Distribution (PSD)

Submitted by Australia

SUMMARY

Executive summary:	This document contains information to support the proposed inclusion of a new test in appendix 2 to determine a TML for coal in the IMSBC Code and to include screening criteria to exclude coals from the need to test them for a TML based on particle size distribution (PSD)
Strategic direction:	5.2
High-level action:	5.2.3
Planned output:	5.2.3.3
Action to be taken:	Paragraph 5
Related documents:	CCC 1/5/8; CCC 2/5/6, CCC 2/5/7 and CCC 2/INF.7

Background

1 Australia has submitted a proposal to amend the IMSBC Code to include a new test in appendix 2 to determine a TML for coal in document CCC 2/5/6.

2 Australia has also submitted a proposal to include screening criteria to exclude coals from the need to test them for a TML based on particle size distribution in document CCC 2/5/7.

3 The annex to this document provides the summary report from Australian Coal Industry's Research program (ACARP) regarding a TML test suitable for coals and the PSD screening criteria that may be applied in order to determine if testing is required.

4 The full report, as independently reviewed by the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) and independently peer-reviewed by the Imperial College in London, is provided in document CCC 2/INF.7.[1]

Action requested of the Sub-Committee

5 The Sub-Committee is invited to take note of the information provided in the annex to this document when considering documents CCC 2/5/6 and CCC 2/5/7.

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[1] Document CCC 2/INF.7 will be available from 10 July 2015.

ANNEX

1. Introduction

This report provides an overview of key outcomes resulting from the research program undertaken into the liquefaction potential of Australian coals during sea transport.
Reference is made to Australia's previous IMO submission CCC 1/5/8 (International Maritime Organisation, 2014) which outlined the research program and the related investigation undertaken to identify an appropriate test method to determine the Transportable Moisture Limit (TML) for coals with a top size of 50 mm.
Research has been coordinated through ACARP (the Australian coal industry's research program), an industry body formed specifically to fund and manage research into coal mining, processing and utilisation of Australian black coals. The TML research program has been managed by representatives of Australian coal producers. The program involved research activities being undertaken by experts in bulk materials handling including the University of Newcastle, Australia and the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO), as well as experts in geotechnical modelling, geotechnical testing, naval architecture and a number of related disciplines.

This research is now complete and the key outcomes are:

1. Clarification of the liquefaction potential of Australian black coals during sea transport.
2. Development of a modified Proctor/Fagerberg test for coal, providing conservative and unambiguous results.
3. Development of screening criteria to identify those coals that exhibit free draining properties under testing, allowing classification as "Group B" only cargoes without the need for further testing. It is recommended that all coals that do not meet this criteria be tested using the modified Proctor/Fagerberg method for coal.

A detailed report describing the results of this research work will be submitted for consideration by CCC2, and will include the outcomes of an independent peer review undertaken by Imperial College London.

2. Context

The TML test methods contained in the International Maritime Solid Bulk Cargoes code (IMSBC code) (International Maritime Organisation, 2013b) provide techniques to determine the TML of a range of bulk cargoes that have the potential to liquefy.
A systematic review was undertaken to establish the potential for each of the three published methods to be extended to coal cargoes with a typical top particle size of 50 mm.
A summary of the findings are presented below.

2.1 Flow Table test

This test is intended for bulk cargoes with a maximum particle size of 7 mm. In relation to the potential to modify the flow table test, Appendix 2 of the IMSBC code states *"it may also be applicable to materials with a maximum grain size up to 7 mm. It will not be suitable for materials coarser than this…"* (International Maritime Organisation, 2013b, p. 335).
The research was unable to identify any literature describing how to upscale the test to suit a material of the size representing typical Australian coal products.
Accordingly, the Flow Table test was not further investigated for application to 50 mm top size coal.

2.2 Penetration test

This test is described as *"generally suitable for mineral concentrates, similar materials, and coals up to a top size of 25 mm"* (International Maritime Organisation, 2013b, p. 342). No guidelines are provided for the treatment of coals with a top size that exceeds 25 mm.

The research identified several test variables which may limit the applicability of this approach for materials of large particle size, including:

- Potential for the penetration bit to lodge onto a large particle, thereby preventing the bit from descending into the sample.
- The material compaction process generated material densities that did not have a demonstrated relationship to the measured in-hold cargo bulk density.
- The acceleration levels generated by the test are inconsistent with the motions likely to be experienced by bulk carriers transporting coal.

For the above reasons, the Penetration test was not developed for application to 50 mm top size coal.

2.3 Proctor/Fagerberg test

The Proctor/Fagerberg test is described as applicable to *"both fine and relatively coarse-grained ore concentrates or similar materials up to a top size of 5 mm."* The IMSBC code recommends that an *"extensive investigation for adoption and improvement is required"* (International Maritime Organisation, 2013b, p. 350) prior to application to coarser materials.
Recognising the effectiveness of Proctor/Fagerberg methods in geotechnical applications, and the adoption for use with iron ore fines, this test was researched at length.
The findings of this research confirmed that a modified Proctor/Fagerberg method is applicable for use on coal where particle sizes are up to 50 mm.

3. Work Strategy

3.1 Research objectives

The research work focused on two main elements:

- Establishing whether coal has the potential to liquefy during shipping; and if so
- Determination of a suitable TML test for 50 mm top size coal.

3.2 Selection of test coals

In order to adequately represent the range of coal products available for export from Australia, a suite of 14 coals was selected on which to base experimental work. These coals were sourced from Australian coalfields spanning over 1,700 km from North Queensland to the Illawarra region of New South Wales.
The suite of test coals contained products:

- From New South Wales (5 coals) and Queensland (9 coals);
- Mined from 8 different coal basins and 10 coal measures within those basins;
- Covering 13 washed coals and 1 unwashed coal;
- Spanning low to high volatile bituminous coals;
- Sold for both metallurgical and thermal application; and
- With particle size distributions representing the normal range of Australian export coals

Producers also provided additional samples of 2 overseas coals for reference testing.

4. Development of modified Proctor/Fagerberg method for coal TML

The Proctor/Fagerberg test described in the IMSBC Code has been modified to allow application to coal with a top size of 50 mm.
The research identified the following areas for modification:

- Detailed sample preparation to yield valid results for 50 mm top size coal;
- Increasing the size of the testing apparatus to suit the maximum particle size of test samples;
- Selection of a lower compaction energy tamping hammer in order to match the measured in-hold bulk density for coal cargoes.
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Appendix 2 of the IMSBC code states the Proctor/Fagerberg *"method should not be used for coal or other porous materials"* (International Maritime Organisation, 2013b, p. 350).
To address this concern, the following areas of the Proctor/Fagerberg method were researched and subsequently modified:

- Ensuring that coal particles were not degraded during the compaction and testing process; and
- Allowing sufficient time between the moisture addition to a test sample and subsequent testing to ensure moisture is evenly distributed into internal pores and fissures of the sample.

The results of these investigations confirmed that the modified test procedure resulted in no degradation of material and that sample moisture distribution was adequate to ensure repeatable test outcomes.

5. Determining the Group Classification of a Cargo

Using the suite of 14 test coals, the research identified 8 coals where water was observed to leak from the test cell prior to the sample reaching the required 70 per cent saturation level. Cyclic stresses induced within a cargo during a voyage through severe storm were mathematically modelled and compared with the strength of these coals in cyclic triaxial testing. In all cases, these coals were found to have sufficient material strength to avoid liquefaction.
Consequently, coals that are observed to leak prior to reaching the 70 per cent saturation level are considered to be free draining, and it is recommended that they should be classified as Group B only cargoes.
The Transportable Moisture Limit of a Group A and B coal is defined as the moisture content where the compaction curve crosses the 70% saturation line.

6. Supporting Studies

6.1 Coal bulk density and cone penetration testing

In order to understand the appropriate bulk density at which to carry out Proctor/Fagerberg testing, three dimensional laser surveying was used to measure the volume occupied by the coal cargo in ships' holds. A total of 8 coal cargoes were surveyed, and in two cases, the cargo hold was again surveyed at the discharge port. Bulk density was calculated from the measured volumes and mass of coal loaded.
Additionally, to investigate the change of bulk density with cargo depth, in-hold cone penetration testing was conducted at the load port for one cargo.
This density data was subsequently used as the basis for selecting the appropriate compaction energy level for the hammer in the modified Proctor/Fagerberg test. The density data was further used as an input for cargo modelling and for setting cyclic triaxial testing conditions.

6.2 Modelling of vessel motion

Mathematical modelling was used to calculate the vessel motions (response amplitude operator data) for a Handymax vessel carrying coal when subjected to severe storm conditions in a beam sea. The Iron Ore Technical Working Group reported that the heave and roll acceleration components for a Handymax vessel are up to twice those experienced by Cape Sized vessels (International Maritime Organisation, 2013a, p. 4). Hence modelling a Handymax vessel represents the "worst case" scenario for understanding potential liquefaction for cargoes exported from Australia.

6.3 Cyclic triaxial testing

Cyclic triaxial testing is used extensively in geotechnical engineering to evaluate the potential for soil liquefaction from cyclic loading events, such as earthquakes and wave motion impacts on marine structures.
The Australian coals evaluated in this research were subject to CTT under conditions matching those identified through vessel motion modelling, and using confining pressures matching those measured at the base of a full cargo hold.

Within this study, CTT was used to determine:

1. Response of fully saturated coals to cyclic stressing in order to assess pore water pressure development and resistance to liquefaction.
2. Resistance to cyclic stresses and liquefaction for coal at the proposed TML, in order to assess the safety of the proposed Transportable Moisture Limit.

Figure 1 shows the results of CTT conducted on the suite of test coals. It presents the cyclic stress ratio (CSR) developed over the measured number of cycles to failure by liquefaction for each coal and indicates the ability for a coal to resist a particular stress condition.
This chart is referred to as an S-n curve.

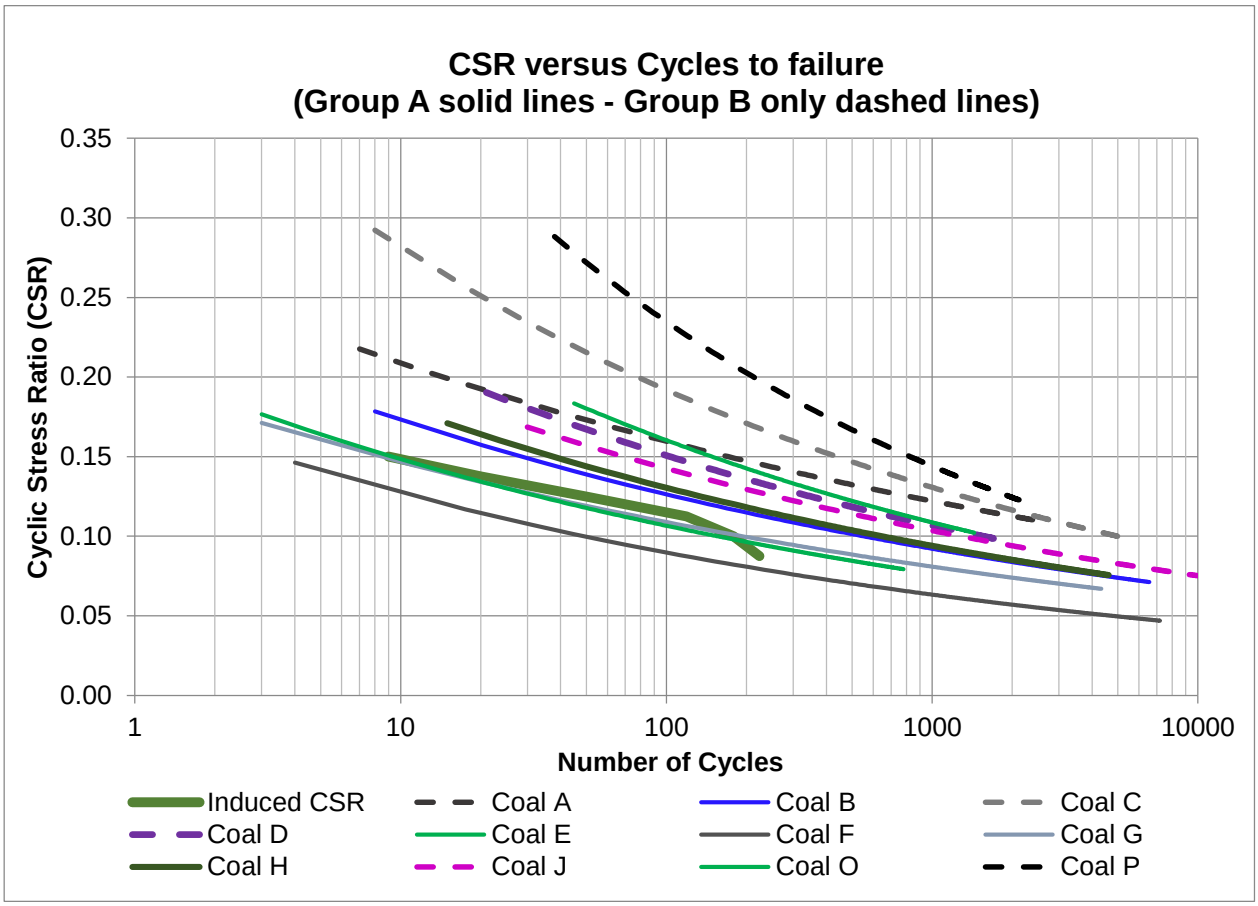

Figure 1 – Comparison of coal CSR (saturated) to the Induced CSR in a Handymax

7. Mathematical modelling of coal liquefaction

7.1 Cargo cyclic stress modelling

Finite element modelling was undertaken to determine the induced cyclic stress ratio within a coal cargo as a vessel responded to a severe storm event.

This modelling allowed calculation of the induced cyclic stress ratio at each node across a cargo cross section. The average induced CSR line for a Handymax vessel is plotted in Figure 1 above and Figure 2 below.

By comparing the resistance to cyclic stress of the test coals to the induced CSR line, it is possible to identify coals with adequate resistance to avoid liquefaction from those that may be prone to liquefaction under fully saturated conditions.
In Figure 1 coals found to be Group A using the modified Proctor/Fagerberg method for coal are indicated with a solid line. Coals found to be Group B only are indicated with a dashed line.

The cargo cyclic stress modelling generated the following conclusions:

1. Every coal that was identified by the modified Proctor/Fagerberg method for coal as Group B only (plotted as dashed lines) had its resistance S-n curve plot above the induced CSR curve. Hence such coals are not able to liquefy under the worst case storm conditions modelled.

2. Coals F, G and O (all of which are identified as having Group A properties) have at least part of their resistance S-n fall below the induced CSR curve. Finite element modelling and CTT confirmed these coals are correctly classified as Group A by the TML method.

3. Coals B, E and H each have their resistance CSR curve fall above the Induced CSR curve, despite being identified by the modified Proctor/Fagerberg method as being Group A and returning a TML value. This is a safe outcome which demonstrates that the modified Proctor/Fagerberg test is inherently conservative, and indicates that whilst the test may identify a Group B only coal as Group A and B, it will never be the reverse.

7.2 Safety evaluation of TML determination by the modified Proctor/Fagerberg method

Figure 2 compares the induced CSR curve from the worst-case storm modelling with the resistance to cyclic stress measured by CTT when a coal is tested at the TML established by the modified Proctor/Fagerberg method. This figure indicates that the material will not be liable to liquefaction when shipped at or below its determined TML as the coals resistance to cyclic stress exceeds the induced CSR.
Hence the modified Proctor/Fagerberg method for coal provides a safe methodology for the determination of the TML.

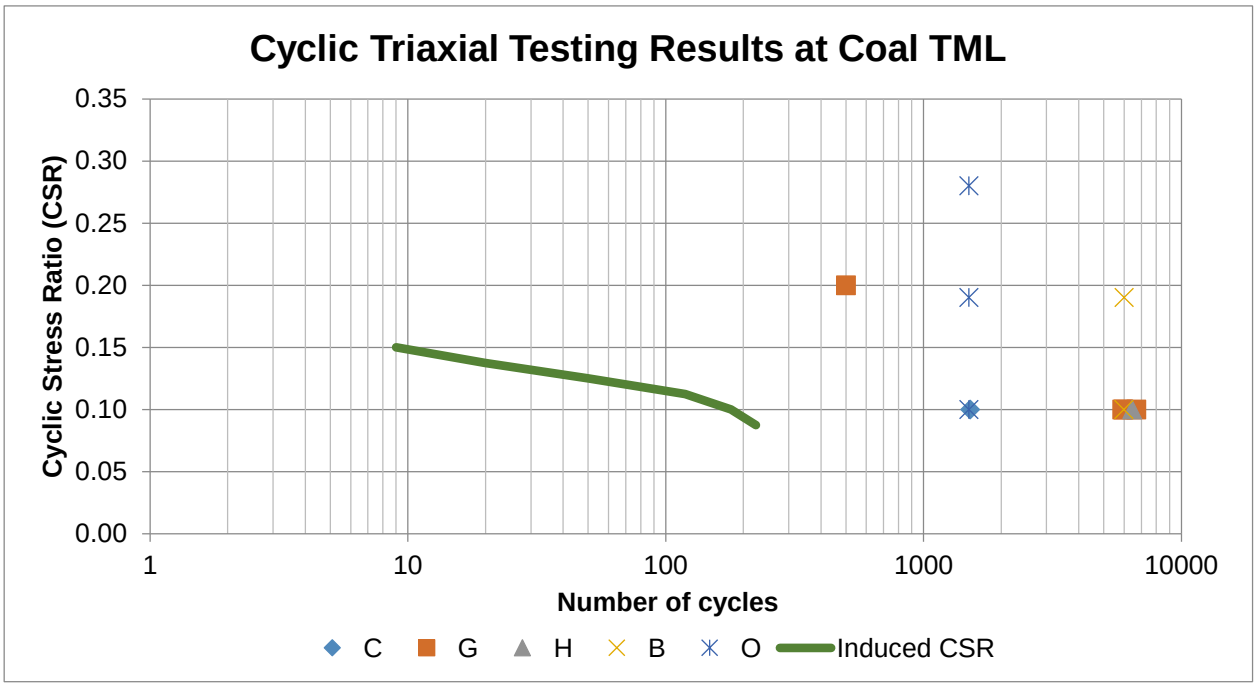

Figure 2 - Comparison of coal cyclic resistance at TML and induced CSR

8. Application of the modified Proctor/Fagerberg method for coal to blended cargoes

Research was undertaken to investigate the effects on the TML of coal cargoes formed by blending; a common requirement for coal shippers. Testing included combinations of Group A and B, and Group B only coal types to understand the impacts on TML levels when different component coals were mixed to form a blended cargo.

The following outcomes were observed.

1. Where all component coals in the blend are known to have Group A properties:
    - The blended coal was always found to be Group A.
    - The TML of the blended coal was further found to be no lower than lowest TML value of any of the component coals.

2. Where a Group A and B coal component(s) was blended with a Group B only component(s):
    - The blended coal may be Group A (and B) or Group B only.
    - The TML of the blended coal was found to be no lower than the lowest TML of the component coals with Group A properties contained within the blend.

3. Where all component coals are determined to be Group B only coals;
    - The blended coal was always found to be Group B only.

As a result of these observations it is recommended that:

> In the case where a blended coal cargo contains at least one coal component with Group A properties, the blended cargo shall be declared as Group A and B, and the TML for the cargo should be nominated as the lowest TML value of any of the individual coal components with Group A properties contained within the blend.

These outcomes have been incorporated into Section 5 of the Modified Proctor/Fagerberg Method to provide guidance for the safe management of blends.

9. Cargo Group Classification Criteria based on particle size distribution

Following the initial phase of commercial testing using the modified Proctor/Fagerberg method for coal, both the TML test results and particle size distribution analyses were collected for 105 different coal products. This provided a data set to further investigate evidence of a functional relationship between the Group classification of materials and their inherent particle size distribution.
It was found that all coals that satisfied the following size criteria were determined to be Group B only when using the modified Proctor/Fagerberg method for coal:

≤ 10% by weight of particles passing 1 mm, or
≤ 45 % by weight of particles passing 10 mm

The group classification of the 105 test coals is shown against these criteria in Figure 3.
It is recommended that prior to utilisation of the modified Proctor/Fagerberg method, coals may be firstly assessed for particle size distribution and those which satisfy the above criteria may be declared as Group B only.

For all coals that do not meet these criteria, transportable moisture limit testing using the modified Proctor/Fagerberg method shall be undertaken.

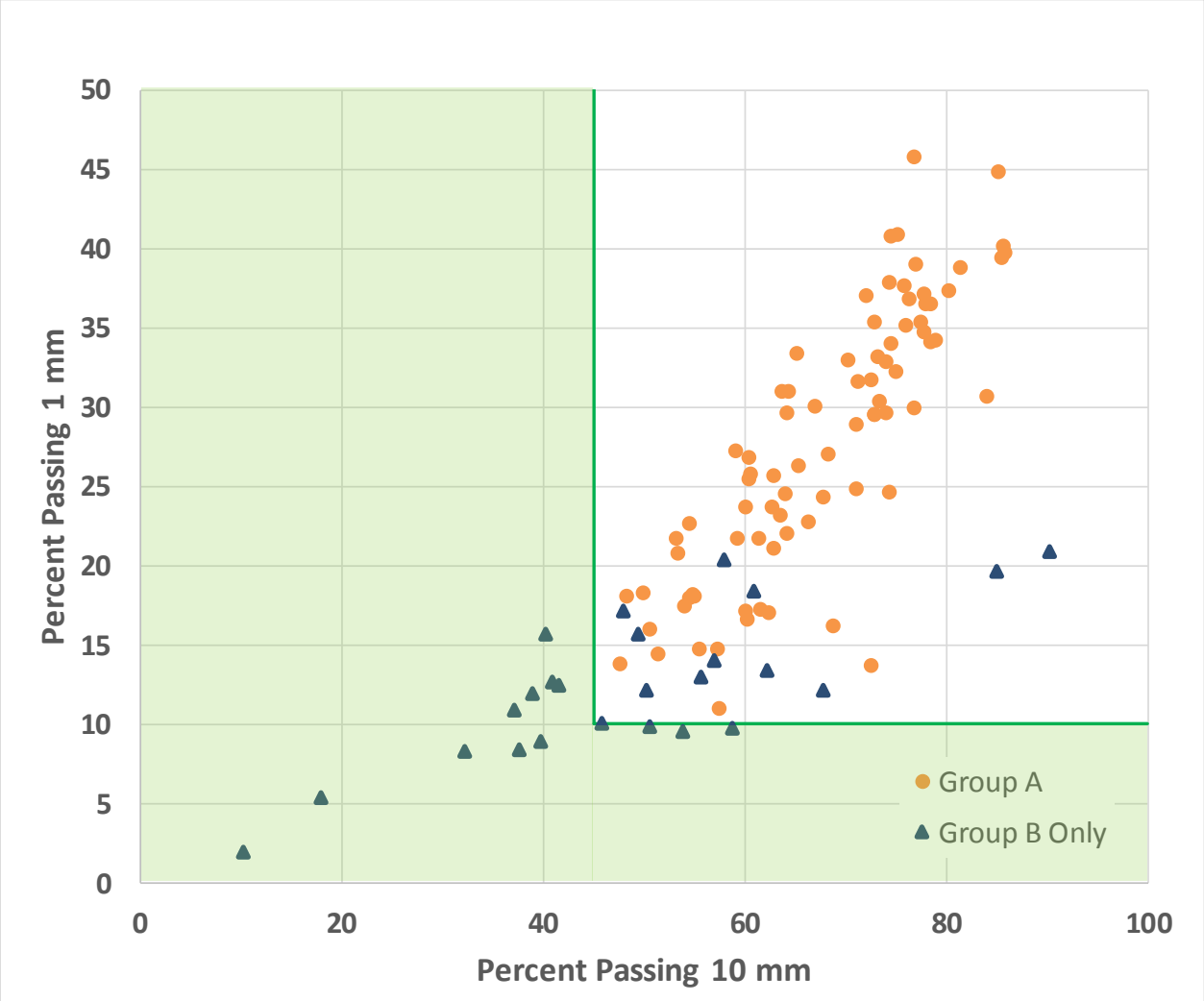

Figure 3 - Graphical representation of size criteria with Group A and Group B only coals distinguished

10. Summary

The research conducted by the Australian coal industry has confirmed that there are some coal types that need to be declared as Group A (and B) products, and there are some coals that may be declared as Group B only.
Criteria based on particle size distribution have been established that can identify Group B only coals.

For coals that are unable to be classified as Group B only, a modified version of the Proctor/Fagerberg method has been proposed for use on coal with a top size of 50 mm.

11. Recommendations

It is recommended that:

1. The following table be included in the Coal Schedule in Appendix 1 of the IMSBC code allowing some coals to be classified as Group B only without the requirement to test for TML.

Cargo property evaluation	Result	Action
≤ 10% by weight of particles passing 1 mm, or ≤ 45 % by weight of particles passing 10 mm	TML testing not required	Declare cargo as Group B only
All other coals	Cargo may be Group A	TML testing required

2. The "Modified Proctor/Fagerberg method for Coal" (ACARP, 2015) be adopted for application to coal cargoes transported in accordance with the Coal schedule in Appendix 1 of the IMSBC code.

12. References

ACARP. (2015). *Modified Proctor/Fagerberg Method for Coal.* Brisbane: ACARP.

International Maritime Organizsation. (2013a). *DSC 18/INF.11 - The technical working group (TWG) report #2 "Marine Report".* London: International Maritime Organization.

International Maritime Organization. (2013b). *IMSBC Code - International Maritime Solid Bulk Cargoes Code incorporating amendment 02-13 and supplement.* London: International Maritime Organisation.

International Maritime Organization. (2014). *CCC 1/5/8 - Australian coal industry liquefaction research project.* London: International Maritime Organisation.