



Flow properties of coal



This Australian Standard® was prepared by Committee MN-001, Coal and Coke. It was approved on behalf of the Council of Standards Australia on 6 August 2017. This Standard was published on 30 August 2017.

The following are represented on Committee MN-001:

- Australasian Institute of Mining and Metallurgy
 - Australian Coal Industry Reference Samples
 - Australian Coal Preparation Society
 - Australian Energy Council
 - Coalfield Geology Council of NSW
 - CSIRO
 - Department of Natural Resources and Mines, Qld
 - Minerals Council of Australia
 - National Association of Testing Authorities Australia
 - University of Newcastle
 - University of New South Wales
 - University of Queensland
-

This Standard was issued in draft form for comment as DR AS 3880:2016.

Standards Australia wishes to acknowledge the participation of the expert individuals that contributed to the development of this Standard through their representation on the Committee and through the public comment period.

Keeping Standards up-to-date

Australian Standards® are living documents that reflect progress in science, technology and systems. To maintain their currency, all Standards are periodically reviewed, and new editions are published. Between editions, amendments may be issued.

Standards may also be withdrawn. It is important that readers assure themselves they are using a current Standard, which should include any amendments that may have been published since the Standard was published.

Detailed information about Australian Standards, drafts, amendments and new projects can be found by visiting **www.standards.org.au**

Standards Australia welcomes suggestions for improvements, and encourages readers to notify us immediately of any apparent inaccuracies or ambiguities. Contact us via email at **mail@standards.org.au**, or write to Standards Australia, GPO Box 476, Sydney, NSW 2001.

Australian Standard®

Flow properties of coal

Originated as AS 3880—1991.
Second edition AS 3880:2017.

COPYRIGHT

© Standards Australia Limited

All rights are reserved. No part of this work may be reproduced or copied in any form or by any means, electronic or mechanical, including photocopying, without the written permission of the publisher, unless otherwise permitted under the Copyright Act 1968.

Published by SAI Global Limited under licence from Standards Australia Limited, GPO Box 476, Sydney, NSW 2001, Australia

ISBN 978 1 76035 876 1

PREFACE

This Standard was prepared by the Standards Australia Committee, MN-001, Coal and Coke, to supersede AS 3880—1991, *Bin flow properties of coal*.

The objective of this Standard is to provide laboratory techniques that allow comparison of handleability of different coals. It also seeks to identify the interface between reliable flow and possible limiting or no flow conditions at various critical locations such as bin outlets or chutes. It outlines a series of three tests to identify the flow material characteristics in instantaneous condition and after time storage, depending on specific design requirements:

- (a) Test 1: Measurement of yield locus. This test permits determination of the stress necessary to shear a coal under a given load.
- (b) Test 2: Measurement of wall yield locus. This test concerns the determination of the rate of shear of coal interfacing with a wall lining material.
- (c) Test 3: Bulk density test. This consists in measuring the compressibility of a coal under various consolidation loads.

Although the emphasis of this Standard is on the determination of flow properties in instantaneous conditions, a method is given for determination of flow properties with time consolidation to simulate conditions during storage. This is of particular importance for those materials whose cohesive strength may change after rest. Further tests can be carried out to determine flow properties at different temperatures and under known vibration conditions using the test equipment described in this Standard. While those tests are mentioned for information purpose, they do not form part of this Standard.

While the laboratory techniques presented in this revision are fundamentally the same as in AS 3880—1991 edition, this revision includes more details on the equipment design and set-up. This aims to allow for all Jenike type shear cells to be similar and the scattering in the results obtained from different labs to be reduced. Another focus of the revision has been to clarify the test procedure. While particular attention has been given to include all details relevant to achieve best repeatability between two similar tests and between labs, it is acknowledged that a certain divergence between results will always remain.

It is recognized that the material presented in this Standard represents a lengthy and complex laboratory procedure that could not yet be successfully simplified despite major research effort. Experience has shown that the level of qualification and experience of the personnel practicing the tests have a significant impact on the quality and meaning of the results. While no certification is required to carry out the test, it is strongly recommended that only suitable, competent and properly trained personnel be engaged for both the tests and material preparation. In fact, due to high dependency between flow properties and moisture content, the reliability of the test results also largely depends on material preparation and handling.

Some coals or other particulate materials may fail to give meaningful results with the Jenike type shear cell. This is because they do not reach the critical consolidation state required for the measurements. It cannot be predicted ahead of the test whether a material can be tested with the Jenike shear cell or not. If not, different tests are required to assess suitable design criteria.

The term ‘informative’ has been used in this Standard to define the application of the appendix to which it applies. An ‘informative’ appendix is only for information and guidance.

CONTENTS

	<i>Page</i>
SECTION 1 SCOPE AND GENERAL	
1.1 SCOPE.....	5
1.2 REFERENCED DOCUMENTS.....	5
1.3 DEFINITIONS.....	6
1.4 NOTATION.....	7
SECTION 2 SAMPLING	
2.1 GENERAL.....	9
2.2 SAMPLE PREPARATION.....	9
SECTION 3 APPARATUS	
3.1 GENERAL.....	10
3.2 TESTER	10
3.3 SPECIFICATIONS	11
SECTION 4 INSTANTANEOUS SHEAR TEST	
4.1 GENERAL.....	14
4.2 PROCEDURE.....	14
4.3 INSTANTANEOUS YIELD LOCUS	19
4.4 COMPLETE FAMILY OF INSTANTANEOUS YIELD LOCI.....	21
4.5 INSTANTANEOUS FLOW FUNCTION	23
4.6 ACCEPTANCE OF RESULTS.....	24
4.7 REPORTING AND PRESENTATION OF RESULTS	25
4.8 PRECISION.....	25
SECTION 5 ADDITIONAL SHEAR TESTS	
5.1 GENERAL.....	27
5.2 HIGH-PRESSURE YIELD LOCUS	27
5.3 TIME YIELD LOCUS	27
5.4 TEMPERATURE YIELD LOCUS	28
5.5 VIBRATION YIELD LOCUS	28
SECTION 6 WALL SHEAR TESTS	
6.1 GENERAL.....	29
6.2 TEST PROCEDURE	29
6.3 WALL YIELD LOCUS	31
6.4 WALL FRICTION ANGLE.....	31
6.5 STATIC ANGLE OF WALL FRICTION	33
6.6 PRECISION OF DETERMINATION.....	33
SECTION 7 BULK DENSITY/COMPRESSIBILITY	
7.1 GENERAL.....	34
7.2 APPARATUS	34
7.3 TEST PROCEDURE	35
7.4 DETERMINATION OF BULK DENSITY.....	36
7.5 PRECISION OF DETERMINATION.....	36

APPENDICES

A	OVERVIEW OF APPLICATION OF FLOW PROPERTY RESULTS IN INDUSTRY	37
B	GUIDE FOR DETERMINATION OF ‘WORST CASE’ MOISTURE CONTENT ON THE BASIS OF SATURATED DRAINED MOISTURE CONTENT	39
C	GUIDE FOR THE SELECTION OF CONSOLIDATION STRESS FOR SHEARING AND EQUIVALENCE BETWEEN MASS, FORCE AND STRESS	41
D	EXAMPLE OF YIELD LOCUS RAW TEST RESULTS FOR 10% MOISTURE COAL	42

STANDARDS AUSTRALIA

Australian Standard **Flow properties of coal**

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE

This Standard sets out a series of tests to characterize the flow properties of coal as the basis for designing equipment to achieve reliable flow at the desired flowrate. Not all the tests described have to be carried out on a material. The selection of the relevant tests depends on the information sought:

- (a) Test 1: Yield locus, covers the measurement of the stress necessary to shear a coal under a given load. From this, the coal flow function can be established, which gives indication of the material cohesive strength. This test also gives output of material characteristics such as internal friction angle, which are required for design calculations and computer simulation purpose.
- (b) Test 2: Wall yield locus, consists of determining the angle of wall friction that describes the interactions between a coal and a selected wall material.
- (c) Test 3: Bulk density, describes the determination of coal bulk density and compressibility. The bulk density is of particular relevance in assessing the flow properties of a bulk material as often, the cohesive strength of a material will depend on its consolidation state reflected by its bulk density.

This Standard is nominally for coal. However, the principles and apparatus may be used for coke and other semi-cohesive particulate materials when a knowledge of flow properties is required.

This Standard also provides some guidance on the presentation of the test results for analysis and design. However, it does not cover the application of the results to industrial design.

NOTE: Appendix A for more information on application of flow properties results.

1.2 REFERENCED DOCUMENTS

The following documents are referred to in this Standard:

AS

- | | |
|--------|--|
| 1038 | Methods for the analysis and testing of coal and coke |
| 1038.1 | Part 1: Coal and coke—Analysis and testing—Higher rank coal—Total moisture |
| 3774 | Loads on bulk solids container |
| 3881 | Higher rank coal—Size analysis |
| ISO | |
| 13909 | Hard coal and coke—Mechanical sampling (series) |

1.3 DEFINITIONS

For the purpose of this Standard, the definitions below apply.

1.3.1 Bulk density

The mass of a sample of particulate solid, including moisture, divided by its total volume.

NOTE: The level of consolidation stress is critical to any measurement of bulk density.

1.3.2 Bulk material

Semi-cohesive particulate material, such as coal and other minerals.

1.3.3 Cohesion

The shear stress at yield under zero normal stress.

NOTE: This parameter is not normally quantified.

1.3.4 Consolidation

The process of permanent volume reduction of a bulk material by application of a consolidating stress.

1.3.5 Critical consolidation (in a shear cell)

The state existing in a bulk sample within a shear cell when the cell stem travel becomes independent of applied shear force.

NOTE: Under these conditions, the bulk material is deforming without change in voidage. The material is said to be in its critical state.

1.3.6 Effective angle of internal friction

The angle with the horizontal axis of a line through the origin and tangent to the Mohr circle through the end point of the yield locus (see Figure 5).

NOTE: The line through the origin is called the effective yield locus.

1.3.7 Flow functions—instantaneous (FF)

For a given bulk material, a plot of the unconfined yield strength σ_c versus the major consolidating stress, values being obtained from the yield loci.

NOTE: This is a measure of the bulk strength or flowability of a bulk material, in a de-aerated state, when first loaded into a bin or consolidated in a shear cell.

1.3.8 Flow function, time storage

For a given bulk material, a measure of the increase in unconfined yield strength of material subjected to standard consolidation conditions for a standard duration, usually 48 h.

1.3.9 Kinematic angle of internal friction

The angle at which the instantaneous yield locus intersects the small Mohr circle defining the unconfined yield strength.

1.3.10 Major consolidating stress

The stress given by the Mohr circle passing through the end point of the instantaneous yield locus and the tangent to the locus (see Figure 5).

1.3.11 Shear apparatus

Equipment for subjecting the material under test to shear deformation under conditions of controlled normal stress.

1.3.12 Unconfined yield strength

The principal stress at an unconfined surface under which an applied stress of equal or greater magnitude tangential to the surface will cause yielding of the bulk material.

1.3.13 Voidage or voids ratio

The volume of the voids within a quantity of bulk material, divided by total volume (voids plus solids).

1.3.14 Yield locus, instantaneous (IYL)

The shear stress versus normal stress curve for plastic failure of an over-consolidated bulk material of given initial voidage; this defines conditions when material flow commences.

1.3.15 Yield locus, time (TYL)

The shear stress versus normal stress curve for plastic failure of a bulk material after being held at rest under a standard stress for a given duration.

1.3.16 Yield locus, wall (WYL)

The locus of shear stress versus applied normal stress on a sample of bulk material moving in contact with a boundary surface or wall. It is the angle determined by the shear and normal stress shown in Figure 8.

1.4 NOTATION

The following quantity symbols are used in this Standard:

A_{cell}	Cross-sectional area of the cell, in mm^2
g	Standard acceleration due to gravity, in m/s^2
h	Compacted height, in bulk density test, in mm
i	Subscript referring to one increment, i.e. one consolidation stress
j	Subscript referring to one given shear normal stress on one yield locus, i.e. for one given shear consolidation stress
m_{cone}	Mass of the empty cone in the saturated drained moisture content test, in kg
m_{drained}	Mass of the cone filled with wet material once the water has been drained but before the material starts drying in the saturated drained moisture content test, in kg
m_{full}	Mass of the cone filled with test material in the saturated drained moisture content test, in kg
m_{h}	Mass of the weight hanger or carrier, in kg
m_{l}	Mass of the lid in the bulk density test, in kg
m_{w}	Weights used in the wall friction test and/or bulk density test, in kg
σ_{i}	Vertical stress due to total vertical load applied at the shear plane during 'sample shear' phase of the shear test, in N/mm^2
σ_{N}	Vertical stress due to the mass applied to the shear lid during the 'sample shear' phase of shear test, in N/mm^2
σ_{s}	Vertical stress due to total vertical load applied at shear plane during the 'shear consolidation' phase of shear test, in N/mm^2
σ_{shear}	Vertical stress due to the mass of the shear lid, shear ring and bulk solid above the shear plane, i.e. contained within the shear ring, in N/mm^2
σ_{t}	Vertical stress due to the mass applied to the twisting lid during the 'preconsolidation' phase of the shear test, in N/mm^2

σ_v	Vertical stress due to the mass applied to the shear lid during the ‘shear consolidation’ phase of the shear test, in N/mm ²
σ_w	Vertical stress applied in the wall friction test, in N/mm ²
σ_0	Vertical stress due to the mass of the shear lid, shear ring and bulk solid contained within the shear ring in the wall shear tests, in N/mm ²
$\sigma_{1,0}$	Vertical stress due to the mass of the lid in the bulk density tests, in N/mm ²
$\sigma_{1,1}$	Vertical stress due to the mass of both the lid and weight hanger in the bulk density tests, in N/mm ²
σ_c	Unconfined yield strength (or stress) of a bulk solid, in N/mm ²
σ_1	Major consolidation stress of a bulk solid, in N/mm ²
ρ_b	Bulk density, in kg/m ³
τ_i	Measured stress at failure occurring during shear test, in N/mm ²
$\tau_{i,prorated}$	A corrected value of τ_i obtained using Equation 7.4(1), in N/mm ²
τ_s	Steady-state shear stress during the ‘shear consolidation’ phase of shear test, in N/mm ²
$\tau_{s,selected}$	The value of τ_s selected for a particular level of consolidation, and used for prorating τ_i values, in N/mm ²
τ_w	Steady shear stress obtained in the wall friction test, in N/mm ²

S E C T I O N 2 S A M P L I N G

2.1 GENERAL

This Section covers the sampling and preparation of the material sample for all three tests described in this Standard.

2.2 SAMPLE PREPARATION

2.2.1 Sample top size

Flow property measurements are carried out on the natural minus 4 mm fraction of a representative sample of the material to be handled. After drying, the sample shall be sieved according to the method set out in AS 3881 to separate the minus 4 mm fraction from larger material. All tests shall be carried out on the minus 4 mm material occurring naturally in the sample. Care shall be taken at all stages of sampling, sample handling and testing to prevent undue breakage into fine particles.

NOTE: Because testing of flow properties is carried out in small sized apparatus, only the finer fraction of the coal can be tested. Since, however, it is the fines that show the poorest flow characteristics, the results are somewhat conservative on average but reflect the worst case conditions likely to be met in practice. It is important to note that the flow of a material with a large fraction of fines is governed by the properties of the fines.

2.2.2 Sample size

The sample for testing shall be prepared by the methods given in the ISO 13909 series. Sufficient sample shall be taken to yield 1 kg of minus 4 mm material after screening. If, however, time-delayed tests are also to be carried out, sufficient sample to yield 5 kg of minus 4 mm material is required.

2.2.3 Sample division

When necessary, the sample shall be divided by riffing or mechanical sample division to provide the required quantity for analysis. Dust loss and size degradation shall be minimized.

2.2.4 Moisture content

The test sample shall be at the nominated moisture level. The moisture content of the full size bulk sample and minus 4 mm test sample shall be measured before and after flow property testing, in accordance with AS 1038.1, and should not vary by more than 0.5% on a mass basis. Samples shall be stored in sealed containers or similar to maintain moisture content. The moisture content of the minus 4 mm in relation to the full size sample shall be determined and recorded on the results sheet (see Clause 4.9).

NOTES:

- 1 For design purpose, the sample should be in that state that reflects its condition during handling. Thus, the sample should be adjusted if needed, for instance by increasing or decreasing its moisture content. When design is to be realized for the most difficult flow conditions, it is recommended to determine the 'worst case moisture content', i.e. the moisture content leading to the worst flow properties. A method to determine the 'worst case condition' based on drained saturated moisture is given in Appendix B.
- 2 While the flow property results are based on the minus 4 mm size fraction, to be meaningful, the results need to be applied to the actual full size variation of the coal being handled.

SECTION 3 APPARATUS

3.1 GENERAL

This Section describes the apparatus to be used to determine both the yield locus and wall yield locus.

3.2 TESTER

A Jenike1-type, direct shear tester, shall be used. Depending on the test, the shear tester will be used in a configuration allowing either determination of yield locus or wall yield locus. For both tests, provision shall be made for a system permitting continuous display and recording of shear/deformation.

The following equipment shall be used:

- (a) A fixed base ring (for determination of yield locus) or sample of wall material (for determination of wall yield locus) on a stable and level frame.
- (b) Shear ring.
- (c) Moulding ring.
- (d) Twisting lid, twisting wrench.
- (e) Shear lid.
- (f) Weight carrier and weights or alternative system allowing application of a defined stress in the centre of the shear cell.
- (g) Spoon, scraper and brush.

Further, a force transducer or load cell with amplifier and recording device, and a measuring stem driven by a motor allowing a constant stem speed of 2.3 ± 0.2 mm/min will be necessary.

Figure 1 shows the various components of the shear cell in the configuration for yield locus measurements. The set-up illustrates the assembly in initial offset position (preconsolidation step) and final maximal offset position (at test completion). For determination of wall yield locus, the base is replaced by a sample of wall material.

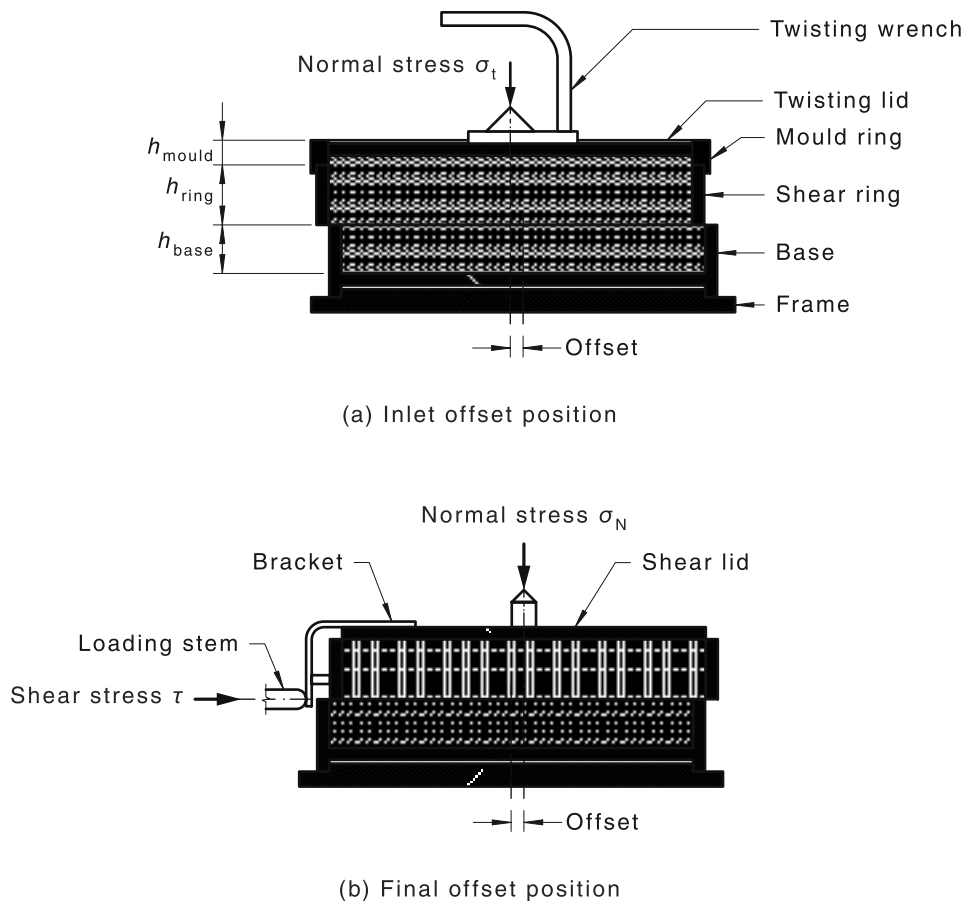


FIGURE 1 SHEAR CELL IN INITIAL OFFSET POSITION (TOP)
AND FINAL MAXIMAL OFFSET POSITION (BOTTOM)

3.3 SPECIFICATIONS

3.3.1 Rings

3.3.1.1 Rings dimensions

3.3.1.1.1 Internal diameter

The rings of the shear cell shall have an internal diameter of 95 mm. Alternatively, when stresses higher than 50 kPa are to be applied, a cell with an internal diameter of 63.5 mm can be used.

NOTES:

- 1 The original shear cell developed and built by Jenike has an internal diameter of 95 mm. An alternative cell with 63.5 mm internal diameter was also developed to allow testing at higher consolidation stresses. However, it has been acknowledged that the actual size of the cell does not affect the test results as long as the proportions diameter/height/ring thickness of the original cell are approximately kept. For historical reasons, it is preferred to use a cell with an internal diameter of 95 mm, or alternatively 63.5 mm for consolidation stresses higher than 50 kPa.
- 2 Besides maximum consolidation stress, the choice of the cell diameter will also depend on the maximum particle size of the sample. As a rule, the cell diameter should be at least 20 times greater than the top size of sample tested. This is to limit boundary effects.

3.3.1.1.2 Ring thickness

The rings shall have a thickness of 3 ± 1 mm.

NOTE: The thickness of the rings determines the travel distance available for a test. A thickness of 3 mm will allow a total travel distance of 6 mm while it is reduced down to 4 mm if the wall thickness is only 2 mm. Experience has shown that 3 mm is a good compromise between result accuracy and test feasibility.

3.3.1.1.3 Rings height

The height of the rings shall be as given in Table 1.

TABLE 1
CELL DIMENSIONS

Element (see Figure 1)	Height mm
h_{base}^a	13 ± 1
h_{ring}	16 ± 1
h_{mould}	12 ± 2

^a internal height

3.3.1.2 Rings material

The rings shall be constructed of a light but strong material with a preference for aluminium. The mass of the shear ring with a diameter of 95 mm shall not exceed 125 g.

NOTE: The mass of the shear ring will affect the total normal stress acting in the shear plane. A maximum mass of 50 g is recommended. Care should be taken that the construction material has stiffness high enough to avoid any risk of deformation during testing under high consolidation stress.

3.3.1.3 Bottom of the cell base

Narrow and shallow grooves with a 90° included angle shall be cut into the bottom of the cell base to prevent relative movement between test material and base.

3.3.2 Other

3.3.2.1 Twisting lid

The twisting lid shall be designed with a system that allows application of a normal stress in the centre of the cell via a weight carrier or similar system while the lid is undergoing rotations in cycles of 90° . The twisting lid shall have a diameter equal to 98% of the internal diameter of the chosen cell to allow for clearance around the lid.

NOTE: The small difference in diameter between lid and rings aims to avoid contact between lid and ring while limiting excessive extrusion of material in the annulus between lid and ring.

3.3.2.2 Shear lid

As for the twisting lid, the shear lid shall have a diameter equal to 98% of the internal diameter of the chosen cell. The shear lid shall be built with a bracket to permit application of a shear stress directly in the shear plane via the loading stem as shown in Figure 2. The pin illustrated in Figure 2 shall have a length slightly greater than twice the ring thickness to allow full travel distance (only restricted by the ring thickness) while keeping the bending moment low. The bracket shall be designed so that the pin is applied at $1/3$ the height of the shear ring.

NOTE: In the case of wall friction tests, using a shear lid with a longer pin will permit increase of available travel distance, i.e. shear distance.

3.3.2.3 *Twisting wrench*

The twisting wrench shall be designed so as to allow for the twisting operation to be carried out without application of any force other than the normal force provided by the weights loaded on the weight carrier. The twisting consists of applying a series of cycles of 90° to the twisting lid with the goal of bringing the test material to approach critical consolidation state.

NOTE: Alternative systems to a twisting wrench may be used provided the cycling of 90° is fulfilled and no force is applied to the cell other than the vertical force due to the weights on the weight carrier.

3.3.2.4 *Frame*

The frame is a fixed structure on which either the cell base or a sample of wall material can in turn be fixed and easily removed. Care shall be taken that the frame is fixed to a structure and level. Before testing, check that the top of the cell base or wall material sample is in line with the centre of the stem, i.e. the stem is in perfect alignment with the shear plane.

NOTE: If the stem is not in perfect alignment with the shear plane, a bending moment will apply during shearing.

3.3.2.5 *Locating screws*

Locating screws or a similar system shall be used to permit positioning and maintaining of the shear ring in its initial position. In its initial position, the shear ring and the base will be offset by about the thickness of the ring as shown in Figure 1. Figure 1 also shows the maximum possible offset in final position after completion of the shear test.

NOTE: The amount of upper shear ring and material offset is limited by the thickness of the shear ring. Smaller offsets may be used provided that the material is critically consolidated under shear by the time the upper cell becomes nominally concentric with the base (see Clause 4.3).

3.3.2.6 *Loading stem*

The motor shall permit continuous travel of the stem at a standard deformation rate of 2.3 ± 0.2 mm/min. The stem can be set to either push or pull the shear ring. Most common set-up uses the stem in a pushing configuration.

3.3.2.7 *Load cell*

The load cell shall have a capacity of 500 N with a measuring accuracy at least equal to 0.1% full scale. The load cell shall have sufficient stiffness to avoid slip-stick phenomenon occurring during stem travel.

3.3.2.8 *Wall material sample*

The minimum size of the wall material sample should be such as to allow shear of the cell on its surface over a distance of at least 10 mm to 15 mm. Generally, a size around 120 mm × 120 mm is recommended.

NOTE: If the surface of the wall sample presents structure such as wear or flow lines, care should be taken to orientate the sample appropriately.