

Round-Robin Validation Exercise for Three Structural Test Methods (open-hole compression, open-hole tension and pin-bearing)

Summary

This Measurement note highlights three new draft methods submitted as ISO new work items by the UK. The drafts cover open-hole compression, open-hole tension and pin-bearing tests.

A round-robin validation exercise has been undertaken to obtain precision data for these methods with four fibre reinforced polymer matrix composite materials representing a range of composite material manufacturing processes were tested. The tests were undertaken by six laboratories, five of which had previously not used the method, according to the draft procedures developed by NPL. The exercise was organised and the results were analysed according to ISO 5275 using 95% confidence limits.

It was found that Repeatability and Reproducibility values were acceptable, the only exception to this was the pin bearing test due to confusion in the pin bearing NWI set up diagram. This has now been rectified.

The precision data will be used to support a UK proposal, prepared by NPL as a New Work Item (NWI) within the ISO work programme. The test method has been studied and improved analysis validated as part of the Composites Performance and Design programme, funded by the DTI.

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Introduction

A round robin-validation exercise has been undertaken to obtain precision data for three test methods:- Open-hole compression, open-hole tension and pin-bearing. The methods have been proposed by the UK as ISO NWI (International Standards Organisation -New Work Items) that are being voted on by ISO countries.

NPL organised a validation exercise covering these tests using four materials, and six test sites to produce evidence of the precision as indicated by within site "repeatability" and between site "reproducibility". The exercise was organised and the results were analysed according to ISO 5275 [\[1\]](#) using 95% confidence limits.

The materials chosen were

Material 1 Chopped strand-mat glass-fibre/ polyester (CSM) hand laid-up

Material 2 Woven glass-fibre/epoxy press moulded

Material 3 Glass-fibre/polyester mixed format pultrusion (PUL)

Material 4 Unidirectional carbon-fibre/ epoxy, autoclave moulded (CFRP)

The participants were:

Centre for Composite Materials, Imperial College

Shorts Brothers plc

BAe Airbus

Fibreforce Composites Ltd

University of Ulster

National Physical Laboratory

The proposed methods are very similar to EN Aerospace drafts based on Airbus Industries Test methods (AITM) [2-5]. The open-hole tension is also very similar to the ASTM D 5766 [6] standard, whereas for the bearing test ASTM D 5961 [5] uses a torqued test, which is not preferred for the reasons given below. The ASTM version of the open hole compression test uses a long specimen supported in a large fixture. The proposed methods are described below

Open Hole Tension (cf prEN 6035 [2], ASTM D 5766 [6])

This uses a 6 mm diameter hole in a 36 mm wide plate equivalent to a "hole diameter diameter-to- plate width" ratio of 6/1. An English size version of 0.25" on 1.5" plate, can be used as an alternative specimen. The standard gauge length for tension tests [7] of 150 mm is used, although failure is focused at the hole. EN ISO 527-4 [7] can be used for the control unnotched test using a 25 mm width specimen.

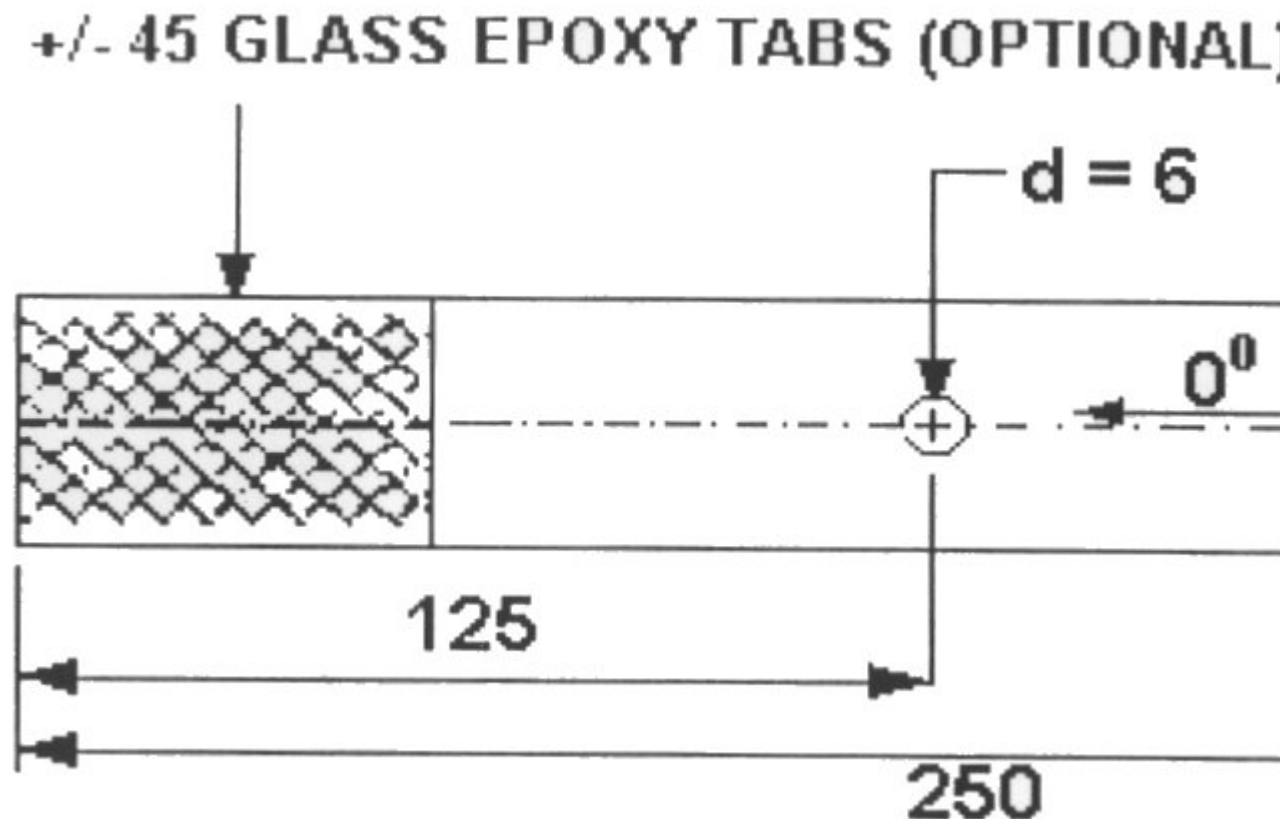


Figure 1 Specimen dimensions for open hole tension test

Open/Filled Hole Compression (cf prEN 6036 [3])

This uses the same 6 mm diameter hole in a 36 mm wide plate format. The standard gauge length for compression tests of 25 mm (AITM prEN 6036 [3] uses a 30 mm gauge length} from EN ISO 14, 126 [8] is used. An unsupported test, if stable, is preferred to those using support fixtures, which do not apply easily repeated conditions and/or where some unknown part of the applied test load is carried by the fixture. The specimen thickness of 4 mm was based on ASTM D3410 recommendations to avoid Euler buckling of the specimen. The 25 mm wide compression specimen in EN ISO 14,126 [8] can be used for the control unnotched specimen. NPL

has used the test for a wide range of materials.

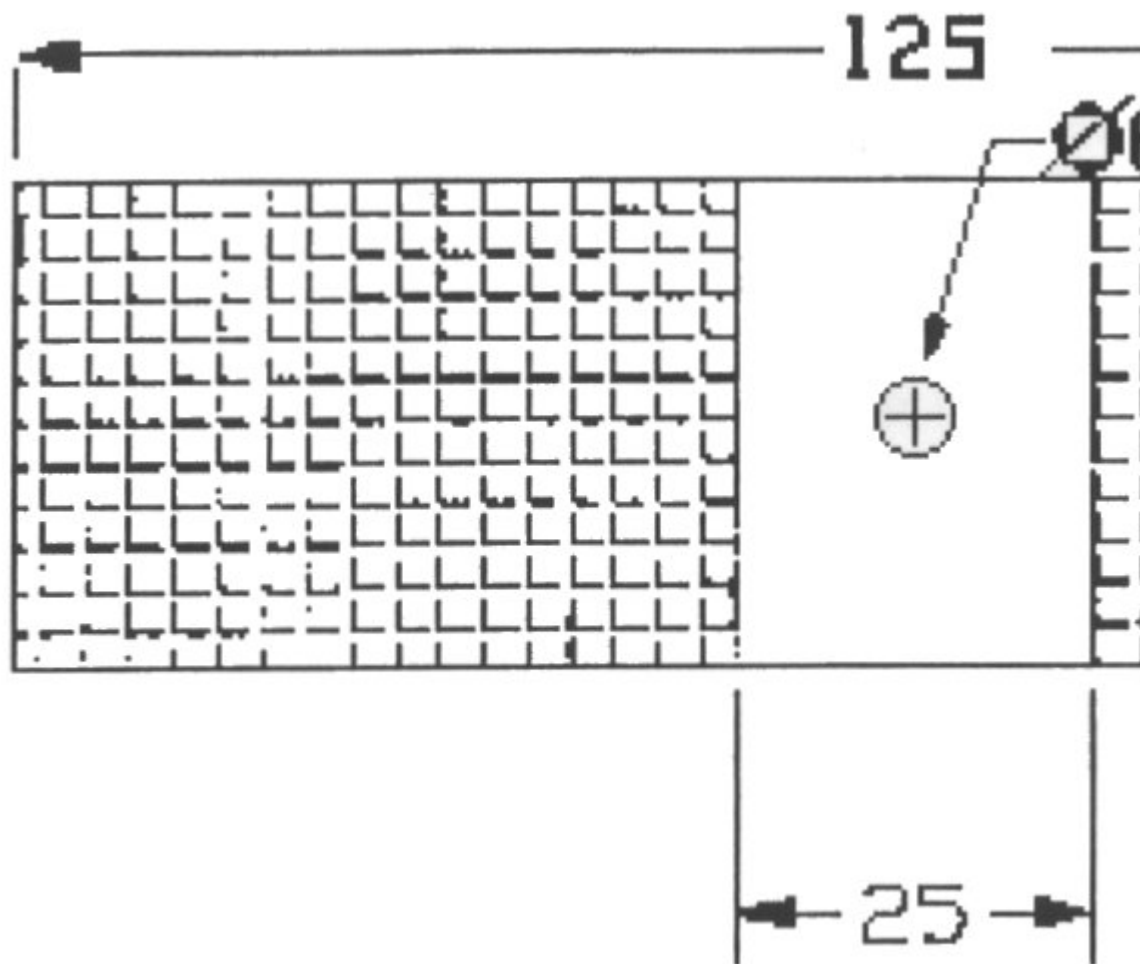


Figure 2 Specimen dimensions for open hole compression test

Pin Bearing (cf pr EN 6037 [4], ASTM D 5961[5])

The plain pin geometry from prEN 6037 is used in the BSI proposal on the basis of recent NPL research using a wide variety of composites to give a basic "material" property test. In contrast, the torqued bolt test has several difficulties concerned with the level of torque, choice of failure criteria, degree of stress relaxation assumed, washer size and thread and composite friction values. The same 6 mm on 36 mm sizes (or 0.25" on 1.5") are used to reduce the cost of specimen preparation, etc. It is proposed in an annex for the NWI that additional tests should be conducted for the proposed joint configuration (eg torqued bolt, rivet) along the lines of the geometries in the ASTM method [5] to produce information specific to application under consideration.

Although these tests are often considered to belong to the aerospace industry and do appear in their material specifications, all types of composites contain holes and bolted or other fittings. For example, the new specification standards being developed for pultruded profiles [9-10] will require, within the mandatory set of properties that must be achieved, both longitudinal and transverse pin bearing strengths. A bearing test is also a requirement of a GRP roofing sheet standard [11]. Further background work on these methods is available from papers published during the test development stage [12-13].

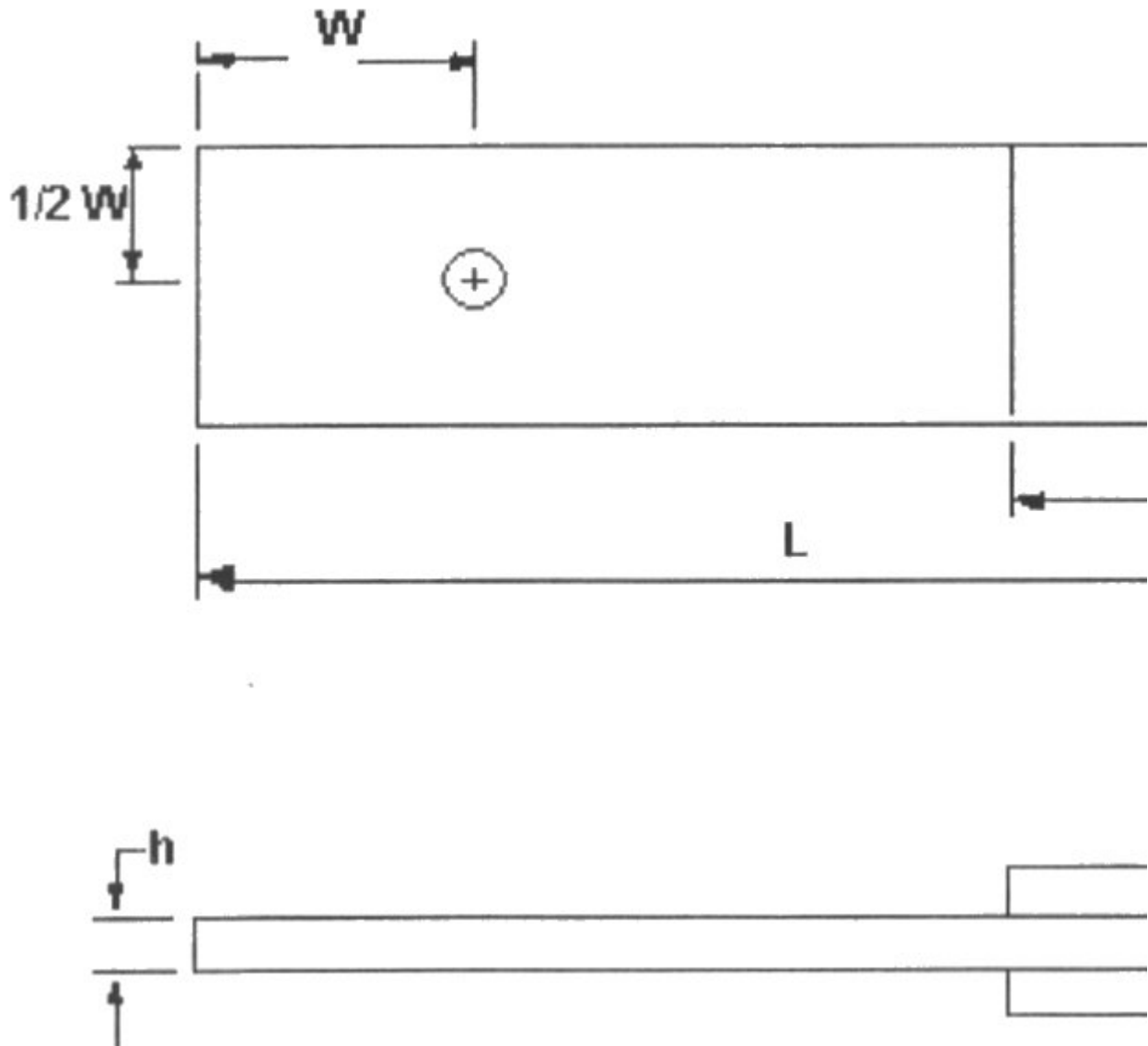
SPECIMEN TYPE 1 WITHOUT HOLE**SPECIMEN TYPE 2 WITH HOLE AND WITHOUT TABS**

Figure 3 Metric specimen dimensions for pin bearing test

Round Robin Procedure

To reduce variability of the results all the specimens were prepared and machined at NPL. The specimens were cut using a water-cooled diamond faced cutting blade and a brad and spur point drill bit. The participants were asked to test six coupons per material per test, after testing the results were sent to NPL for collation and analysis. The analysis of the results for reproducibility and repeatability was undertaken using software written at NPL to the method described in ISO 5725 [1] using 95% confidence limits.

Evaluation Of Results

Repeatability And Reproducibility

The results given below are calculated using the method of ISO 5725 [1], after removal of outliers described in that method. The outliers removed and reasons are given in section 3.2.

Table 1 Repeatability, reproducibility and mean bearing stress for pin-bearing specimens

Material Code	Repeatability Conditions	
	S_r	r
1	33.72	94.42
2	8.80	24.63
3	23.39	65.48
4	36.73	102.84

Table 2 Repeatability, reproducibility and mean notched stress for open hole tension specimens

Material Code	Repeatability Conditions	
	S_r	r
1	5.95	16.67
2	15.55	43.54
3	14.72	41.20
4	8.72	24.42

Table 3 Repeatability, reproducibility and mean notched stress for open hole compression specimens

Material Code	Repeatability Conditions	
	S_r	r
1	7.82	21.89
2	10.72	30.01
3	9.90	27.71
4	4.77	13.35

Table 4 Repeatability and reproducibility values as a percentage of mean values for pin bearing specimens

Material Code	Value as Percentage of		
	Repeatability Conditions		Reproducibility
	S_r	r	
1	8.90	24.91	17.81
2	1.87	5.23	14.14
3	6.89	19.28	14.14
4	4.62	12.96	20.00

Table 5 Repeatability and reproducibility values as a percentage of mean values for open hole tension specimens

Material Code	Value as Percentage of		
	Repeatability Conditions		Re
	S_r	r	
1	7.75	21.71	7
2	8.83	24.72	9
3	8.31	23.25	8
4	2.55	12.93	4

Table 6 Repeatability and reproducibility values as a percentage of mean values for open hole compression specimens

Material Code	Value as Percentage of		
	Repeatability Conditions		Re
	S_r	r	
1	5.53	15.49	5
2	3.93	11.00	4
3	3.71	10.38	3
4	1.40	3.91	3

Note: Definitions taken directly from [1]

Repeatability value, (r): The value below which the absolute difference between two single test results obtained under repeatability conditions may be expected to lie with probability of 95%.

Reproducibility value, (R): The value below which the absolute difference between two single test results obtained under reproducibility conditions may be expected to lie with probability of 95%.

Repeatability standard deviation, (S_r): The standard deviation of test results obtained under repeatability

conditions.

Reproducibility standard deviation, (S_R): The standard deviation of test results obtained under reproducibility conditions.

Data Removed From The Analysis

The following datasets were removed after initial analysis for the reason stated:

Data from site 2 for material 2 failed the Cochran test for outliers and the Grubb and Dixon test for stragglers. Removal of the data in this cell resulted in all statistical tests being satisfied.

Discussion

Pin Bearing Tests

Repeatability standard deviation divided by the mean values were between 1.87% and 8.90% with the higher values for the chopped strand mat and pultruded specimens. This was as expected due to the nature of the materials. Values of around 5% for aerospace materials are acceptable.

Reproducibility standard deviation divided by the mean values were between 14.66% and 20.97%. The reason for this was that in the draft pin bearing standard [Figure 3](#) (as shown in [Figure 4](#)) showed a set-up with a bolt and an extensometer although a clearance gap is specified (i.e. Bolt not torqued against specimen). Because of this some of the tests were carried out finger tight. Previous work carried out at NPL has found that finger tight specimens results can vary from a third higher for discontinuous materials to twice the pin bearing stress for aerospace type materials. Also for pin bearing stress results an extensometer is not needed but is required for torqued bolt tests (e.g. 2%, 4% offset strain). [Figure 3](#) of the NWI has been changed to show a pinned specimen and no extensometer (as shown in [Figure 5](#)).

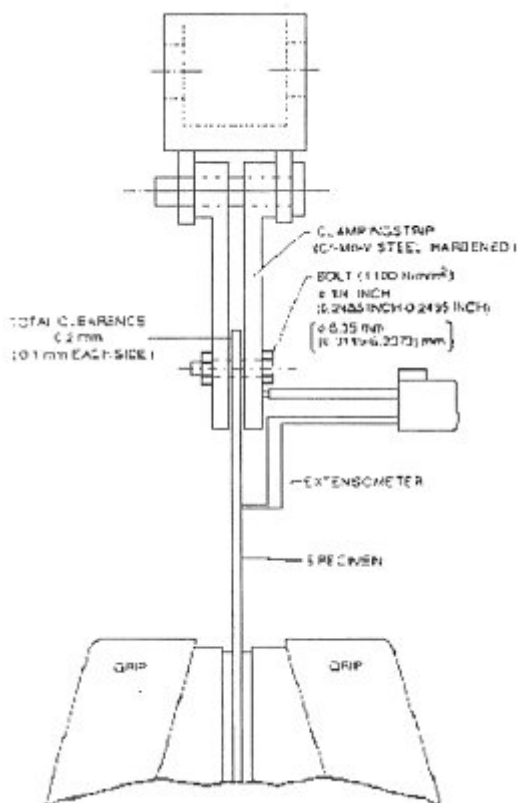


Figure 4 Original figure in pin bearing NWI

Open Hole Tension Tests

Repeatability standard deviation divided by the mean values were between 2.55% and 8.83% of the mean with the higher values for the woven glass epoxy specimens.

Reproducibility standard deviation divided by the mean values were also deemed satisfactory as they ranged from 4.84% to 9.37%. No comments were made by participants about this test as it is similar to other OHT tests used in industry.

Open Hole Compression Tests

Repeatability standard deviation divided by the mean values were between 1.40% and 5.53% of the mean with the higher values for the chopped strand mat specimens. This was as expected due to the nature of the materials.

Reproducibility standard deviation divided by the mean values were also deemed satisfactory as they ranged from 3.34% to 5.60%. Comments were made by a couple of participants that it was difficult to test the specimens using wedge action grips as the short gauge length was making alignment difficult. One participant had to modify their grips so that they could carry out the tests. Other comments made of the test were more due to testing the samples in hot and wet conditions, stating that it would take a very long time for the specimens to be conditioned due to their thickness (ASTM specimens are 2 mm thick). However it should be noted that the conditioning atmosphere has good access to the material controlling failure, i.e. that surrounding the open hole. So the problem may not exist in practice

Conclusions

1. The draft test methods for open hole tension, compression and pin bearing have been validated.
2. The precision data will be used to support UK proposals, for the three New Work Items (NWI's) within the ISO work programme.
3. Apart from the confusion caused by [Figure 3](#) (which has been amended) in the pin bearing standard, participants were able to use the draft test methods without further assistance.
4. Repeatability and Reproducibility values were acceptable, the only exception to this was the pin bearing test due to the error in [Figure 3](#) of the pin bearing NWI.

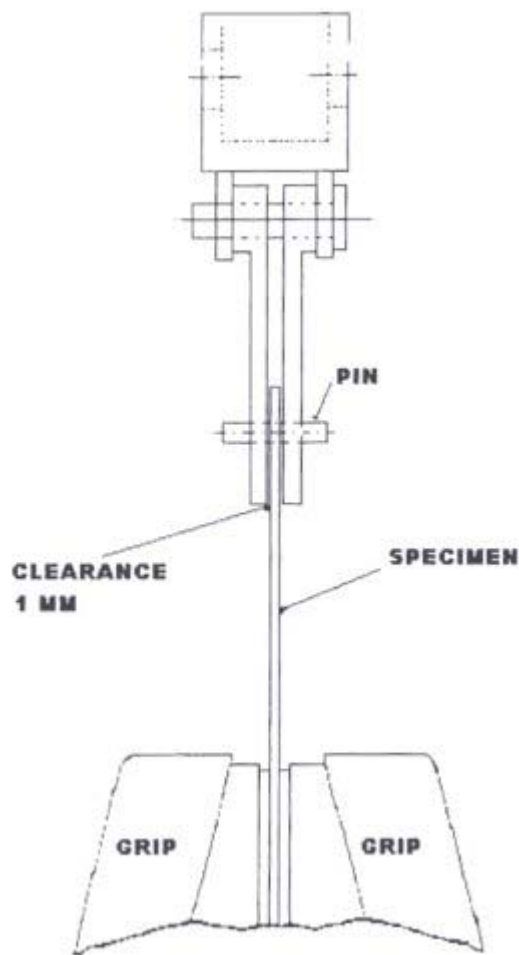


Figure 5 Modified figure for pin bearing NWI

References

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4. prEN 6037 Aerospace Series -Fibre reinforced plastics; Determination of bearing strength
5. ASTM D 5961 -Standard test method for bearing response or polymer matrix composite laminates.
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7. EN ISO 527-4, Plastics -Determination of Tensile Strength. Part 4 Test conditions for isotropic and orthotropic fibre-reinforced plastic composites.
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10. prEN 13706, Reinforced plastics composites-Specifications for pultruded profiles, 1999
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