# Strength Test Facility for Open Source Appropriate Technology (OSAT) 3D Printing

## Description:

A Test Bed and sample Test Pieces for strength / stiffness testing of 3D Printed parts

## Background:

The strength and stiffness of components manufactured using RepRap and other 3D Printing technologies are affected by a number of independent and inter-dependent parameters, including:

1. the generic stock material used (e.g. PLA, ABS, PE, etc)
2. the actual source and condition of the stock material; e.g. it has been reported that PLA filament will absorb atmospheric humidity over time, and this affects its condition when placed using RepRap-type fabrication; it has also been reported that different coloured batches of otherwise nominally identical filament from the same source can exhibit significantly different fabrication properties, and therefore presumably different mechanical properties
3. the tool-path and build parameters which are used to fabricate the component (e.g. filament diameter, layer thickness, number of layers in the surface “shell”, % solid fill vs. % voids used in the core fill, etc)
4. the orientation of the part during printing (filaments parallel or perpendicular to the main load paths, etc)
5. the attributes of the actual printer (print head speed, precision / repeatability of placing the print head, backlash, etc)

When manufacturing components which are intended to have mechanical strength and function, it is necessary to be able to measure the actual strength of materials which can be printed with a particular machine, using a particular set of printing parameters, so that the strength and service life of the component can be predicted, and to assist in the design of new components which will be subjected to loads whose magnitude can be predicted or estimated.

This project came about partly because I am an engineer, and I “need to know” these sorts of things, but was also spurred on by reading an paper on “3-D Printing of Open Source Appropriate Technologies for Self-Directed Sustainable Development” by Pearce, Blair, Laciak, Andrews, Nosrat & Zelenika-Zovko.

[Ref: [www.ccsenet.org/jsd](http://www.ccsenet.org/jsd) “Journal of Sustainable Development” Vol. 3, No. 4; December 2010 <http://www.ccsenet.org/journal/index.php/jsd/article/view/6984/6385> ]

In that paper, the authors conclude inter alia that:

*Full testing of the present abilities of open source 3-D printed parts is needed, including testing a structural part to failure to determine general properties; and analysis/development of necessary testing equipment which could be available to open source 3-D printer users in the field, in order to contribute numerically to the knowledge base on printed OSAT. This can be accomplished by printing a series of beams of different materials, testing them and reporting the results to the open source community.*

This project presents my suggestions towards the development of a standard testing program for 3D printing (and other RP technologies).

## Objectives:

My primary objective in designing the Strength Test Bed and Test Pieces was that they should be easy to manufacture using the actual 3D Printer itself, and any additional “hardware” (“Vitamins”) and instrumentation should be readily available to anyone who is able to manufacture and maintain a 3D Printer. The only “Vitamins” required to undertake testing with this design are:

1. Two short lengths of 8 mm steel rod (as used as the machine axis slides), which act as the test piece support pins, ensuing the test pieces act as simple beams of constant span, with minimal influence of other loading paths.
2. Weights or similar to load the test pieces. These could be readily available standard cast metal weights, if available, or else any convenient masses which must be weighed prior to testing. The test weights are placed on the load pad on the top face of the test piece, ensuring the load is applied as a Point Load at mid-span.
3. A means of measuring the deflection between the underside of the test piece and the Deflection Measuring Pad on the top face of the Test Bed – e.g. a dial gauge or digital calliper. The Deflection Measuring Pad ensures deflection measurements are taken reliably at mid-span of the test piece.
4. Depending upon the strength of the manufactured pieces and the physical size of the available weights, it may be difficult to arrange for the full complement of test weights to be secured on the top face of the test piece. The test piece design allows for the optional use of another piece of 8 mm steel rod which can be bent so as to form a pair of hooks straddling the beam, from which weights can be easily suspended (e.g. tin cans filled with rocks, lead shot, etc)

It should also be possible to manufacture and test a range of test pieces in different orientations. Three key orientations would typically include:

1. “Natural Alignment” - such that the filaments run parallel to the beam long axis, and the layers are aligned with the top and bottom faces of the test piece
2. “Rolled Over Alignment” – such that the part is printed lying “on its side”. The filaments still run parallel to the test piece long axis, but the layers now slice the test piece “vertically” rather than “horizontally” when the test piece is placed in its testing orientation
3. “Vertical Alignment” – such that the test price is printed standing “on end” – this will b a much more “savage” test of the strength between layers, as the tensile beams stresses will act directly on the layers.

I have presented two sample test price geometries; one is a simple rectangular beam, which will allow testing of geometrically identical samples with different % solids core fill. The second is a modified I-Beam which would be a more “savage” test of the strength of components with complex geometry and thin walls, but which should be less sensitive to the % solid fill used (being largely “thin wall” construction). The I-Beam has stiffeners applied at the load concentrations so that its failure will tend to be governed by overall beam failure mode, rather than local crippling of the load points, etc. Both Test Piece profiles should be able to be fabricated on most 3D Printers in any orientation without the requirement for support (assuming the machine is capable of achieving reasonable “bridging”).

The design concept allows for an infinite range of test piece geometry and orientation, but to be generally useful, standardised testing regimes should be developed.

The Test Bed needs to be strong enough and rigid enough that it will survive many cycles of testing, with negligible deformation such that the measured deflections are properly representative of the strength and stiffness of the Test Piece. It is suggested that the Test Bed should therefore be printed with 100% solid fill, for overall rigidity and longevity

## Instructions:

* Print one (or more) Test Beds.
* Print sufficient identical Test Pieces for the testing program. Keep records of the build and print parameters used (material, used, machine settings, % solid core fill, etc). Weigh the test pieces as a record of overall effective density. Where scales of only limited precision are available, weigh five or more identical pieces in a single weighing to get an effective mean sample weight.
* It is suggested that a minimum of three identical test pieces should typically be printed whenever undertaking a formal testing and reporting program, although a single test piece can still yield useful insights into material behaviour when trying to determine a “semi-quantitative” assessment of comparative properties yielded by different printer settings etc. If the set of Test Pieces are printed as a nested suite in a single print run (rather than as a series of sequential print runs), this will ensure all pieces are manufactured under identical conditions, minimising variations due to machine preparation, operator skill, environmental conditions (temperature , humidity, dust), etc. It should be possible to arrange a suite of 5 or even 10 identical test pieces to be produced in a single print run in this way.
* Consider printing sets of test pieces in different orientations when it is desired to understand the 3-dimensional orthotropic characteristics of the material.
* Install steel pins on test bed, and place test piece on pins
* Measure the clearance between the underside of the Test Piece and the Deflection Measuring Pad on the Test Bed
* Apply an initial load increment (well below the anticipated failure load) and measure the mid-span deflection
* Apply additional load increments and measure the deflection at each increment. It is recommended that data points should be entered into a graphing Spreadsheet or similar as it is recorded, to allow trends to be identified immediately (e.g. possible deflection reading errors, non-linear behaviour may indicate onset of failure, etc)
* Repeat for each test piece in a suite, so that statistically meaningful results can be obtained.
* Repeat for different manufacturing orientations, so that the influence of orthotropic material properties can be assessed.

## Additional Work:

It is suggested that the RepRap community should review the design concept as presented here, and attempt some individual testing programs. It is possible that the design concept may need to be modified for broad adoption generally; e.g. larger (or smaller) test pieces may be considered appropriate to be generally representative.

If successful, it is proposed that a formal test regime and reporting system would be developed and published; e.g. either through the RepRap.org website, or other OSAT Community Host. Individual users would test and report their findings. Results could be searched and filtered so as to provide statistically useful data on the practical material properties that can be achieved with different classes of 3D printers and stock material. This information could be used to allow machine users to “benchmark” their own machines, and also as an aid to design and manufacture of components.

Material properties which would be recorded could include (but not necessarily be limited to):

* Effective Bulk Density
* Effective Tensile Strength, Elastic Modulus and Elongation measured along the filaments
* Effective Tensile strength, Elastic Modulus and Elongation between filaments (measured parallel to the laminations)
* Effective tensile Strength, Elastic Modulus and Elongation measured between laminations

## Note on Use of Open Source vs. Proprietary Software:

This project was a “work-in-progress” before I became aware of the OSAT initiative, and was intended mainly for my own entertainment / education, but with a view to sharing with the RepRap community. I created these design s using proprietary “Alibre Design” CAD software, Mathcad and Microsoft Excel workbooks, etc. It is proposed that if the concept is deemed to have general applicability, the source files for all parts should be created in Open Source software (e.g. OpenSCAD), and Open Source software should also be used for record keeping and reporting (e.g. Open Office etc).