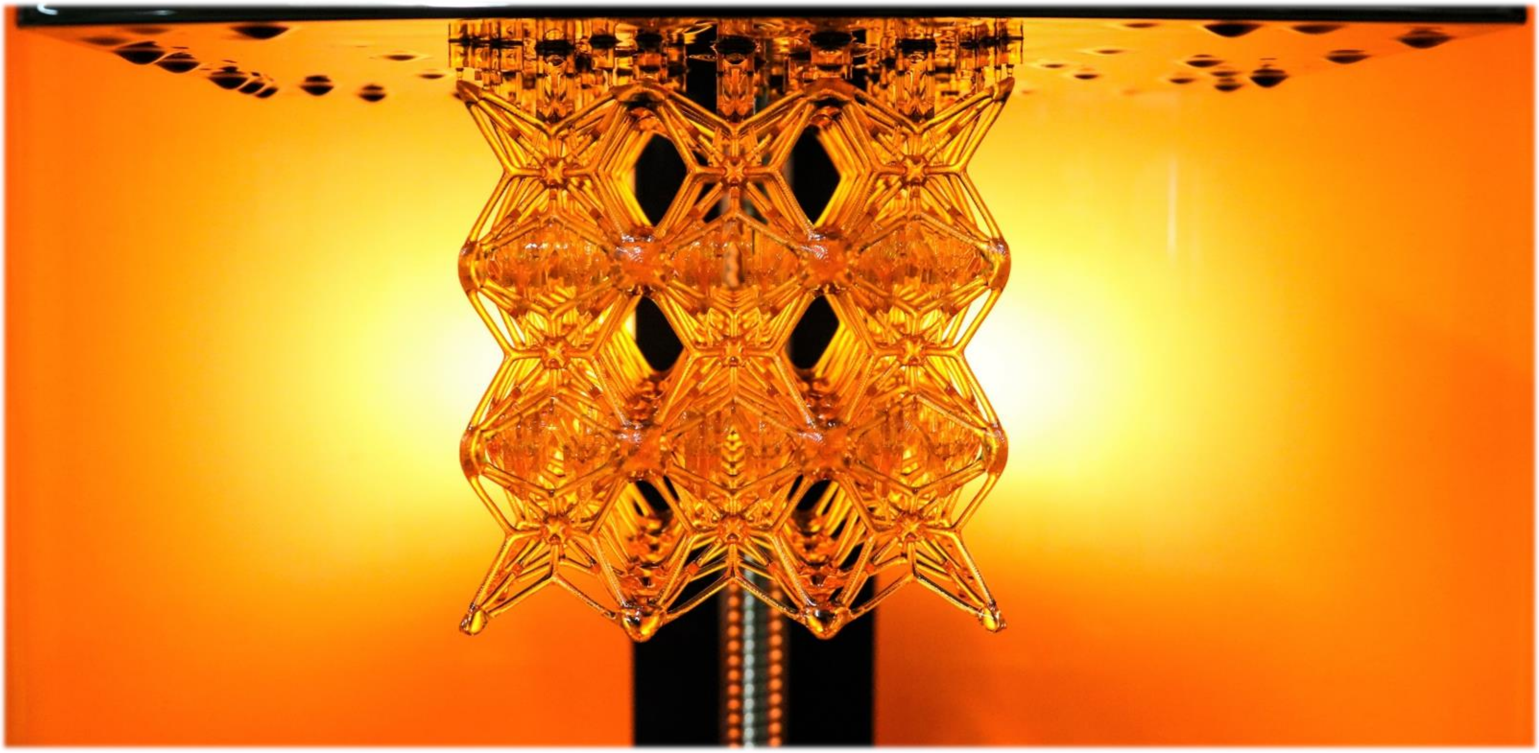

EFFECTS OF PRINT WINDOW MATERIAL ON SEPARATION FORCE OF 3D PRINTED OBJECTS IN DLP SLA PRINTING PROCESSES

Abstract

The purpose of this report is to study the effect of print window materials on the force required to separate each layer of a 3D printed object from the print window in DLP SLA 3D printing processes by comparing NewPro3D's Intelligent Liquid Interface (ILI) with an existing print window material, PDMS (silicone). Using a high-accuracy load cell, the force required to separate a printed cylinder of varying diameter from the print window was measured for both PDMS and ILI to generate trends and draw comparisons. This report finds that NewPro3D's Intelligent Liquid Interface experiences separation forces as low as 18.5 times less than those observed in tests using a PDMS print window and throughout 15 layers of printing, averaged 8.9 times less than PDMS. With these drastically reduced separation forces, NewPro3D can print faster and larger with less support structure, smaller support contact points, and has the ability to print ultra-flexible materials.

NewPro 3D

May 17, 2018

NewPro3D Print Separation Force Test

Introduction

3D printing technologies such as Stereolithography (SLA) and Digital Light Projection (DLP) require support structures on 3D printed objects to support specific features of an object as it prints to counteract separation forces between two flat surfaces, gravity, and bonding forces to the print window. All bottom-up SLA and DLP printers require support structures for objects as their feature orientations deviate from the vertical axis due to gravity forces exerted on the object. SLA and DLP printers also require additional support structure to counteract the force required to separate an object from the print window between each layer known as "separation force". The amount and size of supports required as well as the support contact area can be reduced with a corresponding reduction of separation forces exerted on an object. NewPro3D has developed patented Intelligent Liquid Interface (ILI) technology that has been shown to dramatically reduce the separation forces exerted on an object when compared to the most common print window material, PDMS (silicone). This reduction in separation forces eliminates the need for the mechanical debonding and resin refresh steps required to print using a PDMS print window. The objective of this test is to measure the separation force exerted on an object printed using NewPro3D's ILI technology and compare these forces to those exerted on an object when printed using PDMS.

Objective

The objective of this experiment is to determine the force required to separate the solidified cross-section of an object from the print window using NewPro3D's Intelligent Liquid Interface (ILI) and compare these forces to those measured when printing the same object on a PDMS (silicone) print window.

Purpose

The ability to 3D print objects at high speed with minimal support structures hinges on the ability to separate solidified cross-sections from the print window with minimal force. With a decrease in force required to de-bond an object from the print window, there are many associated benefits to the 3D printing process and post-processing. Decreased separation forces allow for:

- Increased print speed by elimination of the need for any mechanical steps between layers and faster motor movement speed in the upwards direction
- Reduced support contact point size resulting support structures that can be removed without the use of tools, reduced post-processing requirements and reduced surface imperfections at contact points
- The ability to print materials that are highly flexible
- The ability to print objects with large cross-sections
- Decreased object support structures resulting in less wasted material and lower print costs
- Increased dimensional accuracy of printed objects

This report aims to demonstrate the superior release properties of NewPro3D's ILI when compared to the most commonly used print window material, PDMS.

NewPro3D Print Separation Force Test

Methods and Materials

All tests were performed on the NP-1 3D printer produced by NewPro3d. For these tests, the NP-1 printed each vertical layer at a thickness of 100µm with an ascent rate between layers of 2000µm/s. The power density of the light source was measured to be 14.0mw/cm^2 at the surface of the print windows using an Opsytech RM-12 radiometer.

Separation force data was measured by printing a cylinder perpendicular to the build platform that incrementally decreased in diameter every 15 layers (1.5mm) by 5mm. The test started with a 50mm cylinder that then decreased after 15 layers to 45mm, to 40mm and so on down to a final cylinder size of 5mm. This geometry is represented visually in Figures 1 and 2. The file was supported using Materialise Print for DLP software with 1mm contact points. NewPro3D P-121 resin was used to form the test print objects.

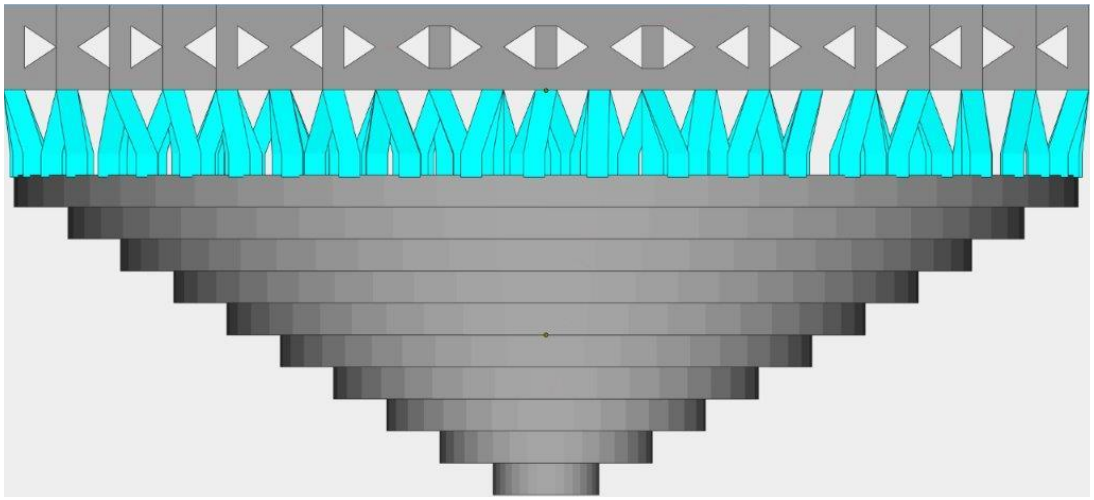

Figure 1: Separation force test print model. Stepped cylinder decreasing in diameter by 5mm with every 1.5mm in vertical print distance

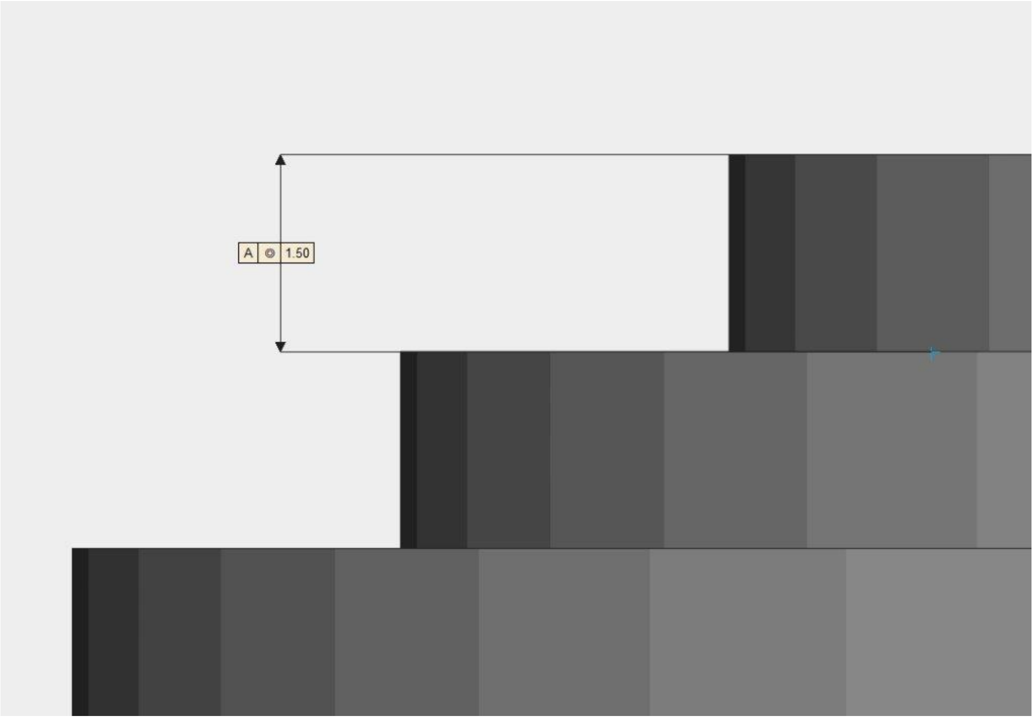

Figure 2: Separation force test print decreased in diameter by 5mm with every 1.5mm of vertical print distance (15 layers)

Separation forces were measured using the ZA1-25 S beam load cell connected to a Model 250 Digital Indicator both provided by Sentran. The load cell is rated for loads up to 25lb and is accurate to 0.02% of its maximum load, or 0.005lb. A custom assembly was designed to integrate this load cell into a build platform on which the test print could adhere to as shown in Figure 3.

Figure 3: Separation force test rig assembly

Print vats were prepared for testing as follows:

a. Intelligent Liquid Interface (ILI)
   i. Clean vat
   ii. Apply new ILI
   iii. Add appropriate resin and fill to ridgeline
   iv. Clamp vat in place
b. Silicone (PDMS)
   i. Clean vat
   ii. Clamp in place using steel bar stock with quick clamps
   iii. Add appropriate resin and fill to maximum line on vat

Once the vats were prepared for printing, the load cell was zeroed and lowered into the vat to begin printing the test object. Separation forces throughout the print were collected via USB connection to the digital indicator and this data was exported to a .csv excel file.

Variables

- Resin temperature – increased temperature results in reduced resin viscosity. All tests were performed at a resin and ambient temperature of 21ºC
- Resin Viscosity – separation forces increase with increased resin viscosity. Identical resins were used with a viscosity of 48cps for all tests to eliminate variability related to resin viscosity
- Separation Velocity – separation forces increase with increased separation velocity. A separation velocity of 2000µm/s was used for all tests
- Acceleration forces – forces due to vertical acceleration of the build platform were too small to measure and for the purposes of this test can be considered negligible
- Part weight – as the test part is being printed, part weight will affect the recorded force readings. As this is a comparison test, the part weight will be identical between each print window material and can be ignored
- Buoyancy force – the relative weight of the build platform will decrease when the build platform descends beneath the surface of the liquid resin. Test prints have been designed with a scaffolding structure thickness that will ensure the test cylinders do not begin printing until the build platform has emerged from the liquid resin.
- Stefan Adhesion Force – Regardless of the material used on the print window, there will be adhesion forces due to the separation of two flat surfaces submerged in liquid according to the equation below in Figure 4. Since this is a comparison test and the objects being printed are identical, each print window material will be equally affected by Stefan Adhesion forces and these forces can therefore be ignored.

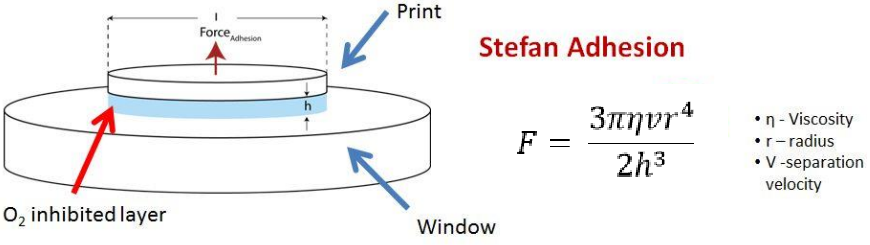

Figure 4: Stefan Adhesion Diagram & Formula

Results and Discussion

Results from separation force tests were exported to an excel file where they could be processed into relevant data. The Model 250 Indicator records load measurements 10 times per second and outputs a value in Pounds. These values were converted from Pounds to Newtons using a conversion factor of 1lb = 4.448N.

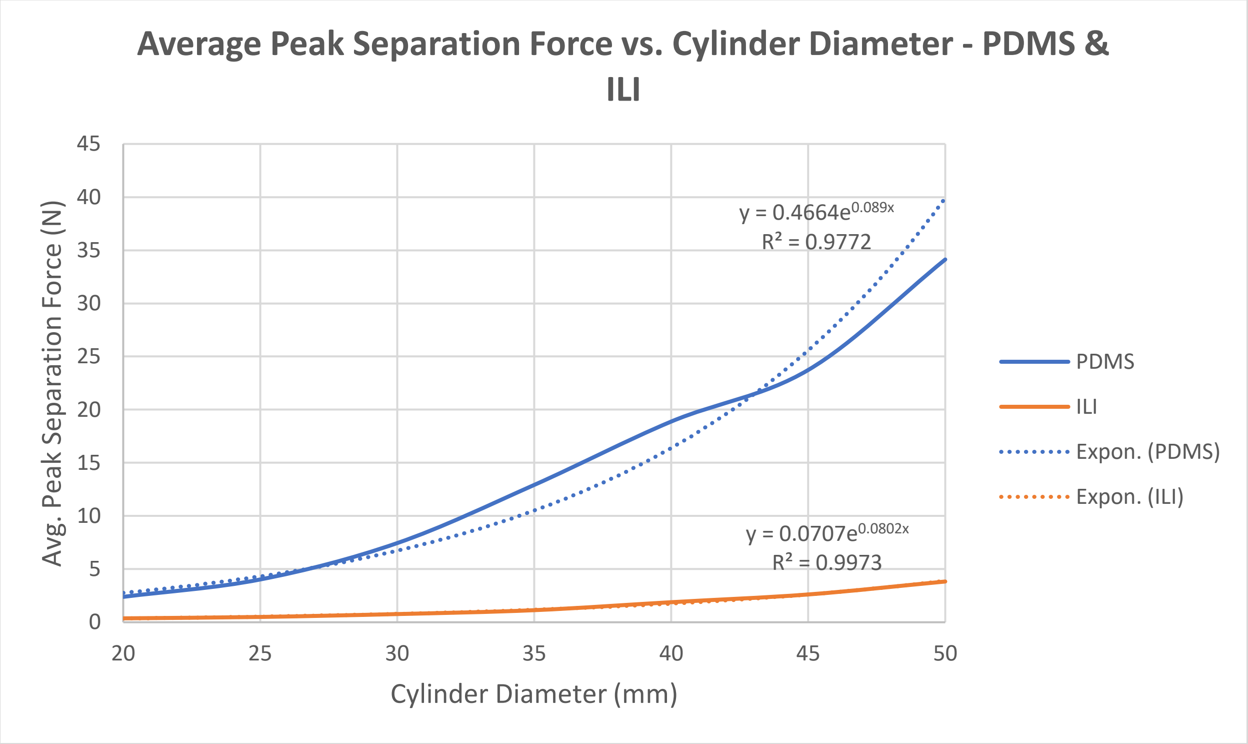

Figure 5: Relationship between average peak separation force and cylinder diameter

Figure 5 shows that separation forces increases exponentially with cylinder diameter. This trend is demonstrated by exponential trendlines with 97.7% and 99.7% R^2 values for Silicone (PDMS) and Intelligent Liquid Interface (ILI) trends respectively also shown in Figure 5.

The results of separation force tests displayed a significant difference between the separation force required to separate an object from the print window when comparing PDMS to ILI. This difference was most pronounced when comparing separation forces of the 50mm diameter cylinder where the force required to separate the part from the print window using PDMS peaked at a value 18.5 times greater than ILI as shown by the trend in Figure 6. The average peak force required to separate a solidified layer from the print window over 15 layers at a cylinder diameter of 50mm was 8.9 times higher for PDMS than for ILI.

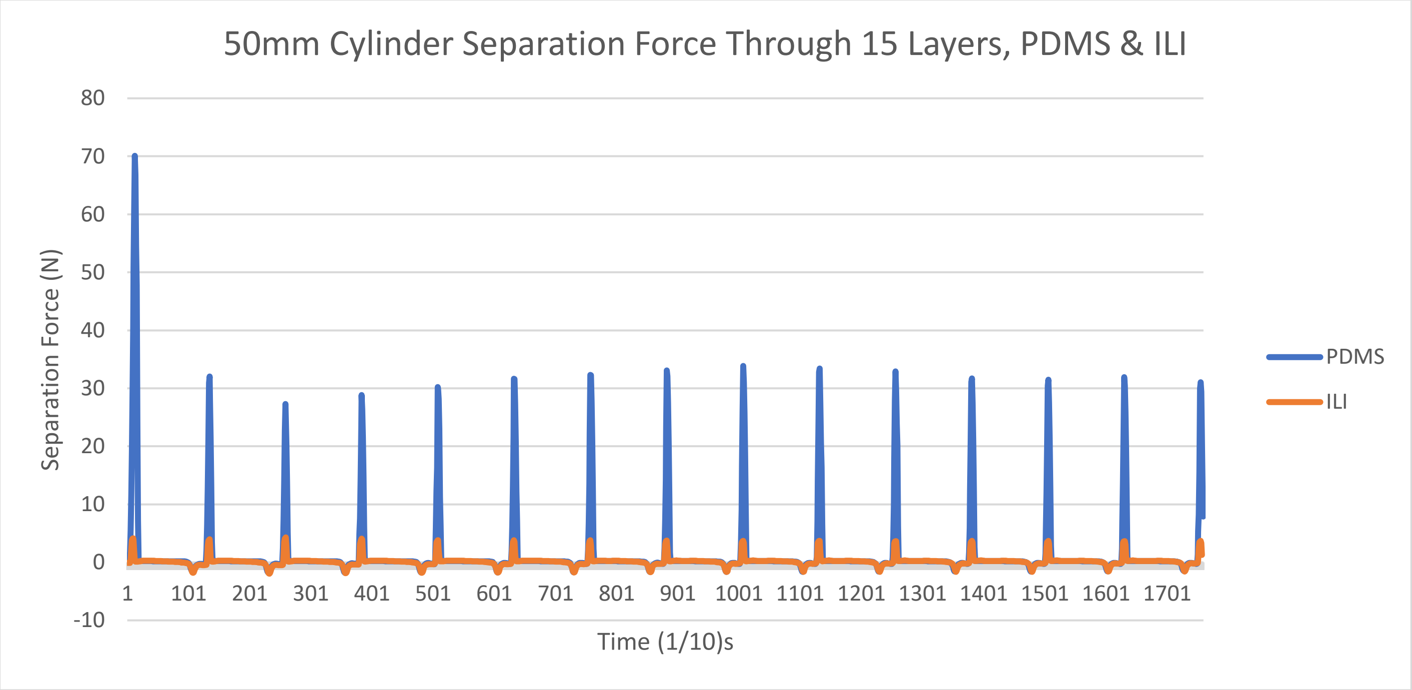

Figure 6: 50mm cylinder separation force throughout 15 layers

Separation force data measured in the ILI test indicated that below a cylinder size of 20mm, separation forces are so low that they eventually approach the accuracy limits of the measurement equipment and the weight of the printed object eventually becomes greater than the force required separate a printed layer from the print window. Because of this, ILI and PDMS are only compared in this report at and above a cylinder diameter of 20mm where part weight does not significantly contribute to measured separation forces. The dimensions of these test prints were also measured after testing to ensure that the objects were printed accurately. All cylinder diameters from 50mm to 5mm for both tests were measured to have printed accurately to within 0.03mm of the CAD model as shown in Table 1 below indicating that variations in part size would not significantly contribute to separation forces

CAD Model Diameter (mm)	Measured Diameter ILI (mm)	Measured Diameter PDMS (mm)
50.00	49.98	50.02
45.00	45.01	45.01
40.00	39.99	40.00
35.00	34.99	35.02
30.00	30.01	30.00
25.00	25.01	25.02
20.00	20.00	20.02
15.00	15.01	15.03
10.00	10.02	10.02
5.00	5.01	5.01

Table 1: Measured cylinder diameter of test objects printed on ILI and PDMS vs CAD model

NewPro3D Print Separation Force Test

Conclusion

The results of this report show conclusively that by using NewPro3D’s Intelligent Liquid Interface (ILI) as a print window material, significantly less force is required to separate a 3D printed object from the print window than when using silicone (PDMS) for the same purpose. This report also shows that the benefits of using NewPro3D’s Intelligent Liquid Interface compared to silicone increase exponentially with increasing part size.