EXPLORING THE MECHANICAL PROPERTIES OF THE POLYJET PRINTED VEROWHITE SPECIMENS

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Abstract
An experimental study was performed to establish the mechanical properties of verowhite material specimens. Four different print modes like, high quality glossy finish, high quality matte finish, high speed glossy and high speed matte was adopted to produce the verowhite specimens using an Objet 260 Connex Polyjet 3D printing machine. Water jet machining process is used to take away the specimens from the 3D printed verowhite boards and also the required specimens for mechanical test are prepared as per ASTM standards. Different mechanical tests like, tensile, flexural, shore hardness and surface roughness were performed on the well prepared verowhite specimens. Experimental results shows that the verowhite material specimens printed with high quality glossy finished mode yield the enhanced mechanical properties than other printed modes.
Keywords: Verowhite material, Polyjet 3D printing, mechanical behaviour.

1. Introduction

In recent years, 3D printing technology plays a significant role in the intricate structures developing sectors. It also reduces the lead time for the prototype design verification, physical prototype invention, prototype development and operational analysis through the undeviating conversion of modeling files into the functional prototypes [1]. The real transformation of CAD files into manufacturing outputs for the complex structures were absolutely execute by the way 3D printing or additive manufacturing with the customized features [2]. Multi- material 3D printing methods development were focused to enhance the different properties and for the efficient fabrication of the structures with multiple material combinations [3]. Newly invented technique specifically called as 3D printing technology, which is used to manufacture the complicated three dimensional structures by the way of layer by layer fabrication [4]. Various convoluted objects were reproduced all the way through the prompt development of additive manufacturing technique to overcome the different drawbacks of the conventional manufacturing techniques [5]. Pats are generated using a layer-by-layer approach in an additive manufacturing (AM) technology. This approach is completely differed from normal traditional manufacturing techniques [6]. 3D printing technique are always allows for versatile shapes to be prepared with a degree of design freedom unattainable with conventional developed methods. Conversely, the thermoplastic material's mechanical properties are not matched up to the pervasive materials for engineering applications [7]. Three structures namely, re-entrant honeycomb, conventional honeycomb, and truss cellular were fabricated using 3D printing technique and the mechanical properties like, bending stiffness, strength and energy absorption were calculated [8]. Enhanced mechanical properties were obtained in the new class of reinforced composites for an extensive variety of engineering applications and promote to generate the multifunctional materials from the 3D printing techniques [9]. Deformable composite materials and stretchy structures were shaped from soft rubber materials by using Polyjet multi-material 3D-printing method [10]. Mechanical properties of the narrative kinds of 3D printed interpenetrating phase composites (IPCs) with intermittent architectures were investigated and the fabrication was completed by means of Polyjet 3D printing technology [11]. Modulus of elasticity, strength of the 3D printed prototype under compression and Poisson's ratio were testified and these results were similar to the coal rock prototype [12]. In this present experimental study, different mechanical properties of the Objet 260 Connex Polyjet 3D Printer printed Verowhite specimens which are printed in four various print modes were established and compared with each other.

ISSN- 2394-5125 VOL 7, ISSUE 04, 2020

2. Experimental methodology

2.1 Verowhite Resin Materials (Opaque Polyjet Resin)

Verowhite Resin 3D prints create objects which are particularly smooth and precise. This material is perfect for ornamental objects. Verowhite (opaque white Polyjet resin) is also often used by large companies when prototyping new designs, this Polyjet material offers the possibility to create really realistic prototypes. But this resin can also be used for creating end-use products due to its high accuracy and smooth surface. Thanks to additive manufacturing everyone from beginning designers to experienced professionals can also benefit from the great freedom of design offered by this material. Compared with a standard engineering plastic such as standard ABS thermoplastic, Verowhite photopolymer is stronger and stiffer regarding the industry's average for tensile strength, flex strength, and flex modulus. However, Verowhite (rigid opaque resin) is more similar to acrylic than ABS, PC, polypropylene or polyamide. This is why the Verowhite material is generally designated for light functional testing, patterns, prototypes, and models. The Verowhite Resin (opaque Polyjet resin) is suitable for large volumes with small details on it but it is not suitable for wired shapes. However, this material is perfect to give life to complex designs. With respect to water qualities, Verowhite resin is water-resistant but not waterproof. Thus the 3D object must not rest in contact with water for extended periods of time. In terms of temperature, if the Verowhite 3D printed part is subjected to heat above 50°C (122°F), it is possible that the physical form of the object can be significantly altered. Some mechanical properties of the verowhite material are shown in table.1.

Table 1. Mechanical properties of verowhite material

roperty	Polymerized density	Tensile Modulus	Tensile strength	Elongation at break
Unit	g/cm^3	MPa	N/mm^2	%
Value	1.17 – 1.18	2495	50 -65	10 – 25

2.2 Objet 260 Connex Polyjet 3D Printing Machine

The Objet260 Connex is a revolutionary 3D printing system in the world of true-product realism. This compact, attractively priced 3D printer is the newest machine in Objet's line of multi-material 3D systems.

The 260 Connex enables a variety of rapid prototyping applications in various industries, including dental, medical, engineering and manufacturing to name a few. The machine allows for designers and engineers to produce prototypes to match their intended end-product like no technology currently available. Utilizing Objet's breakthrough Polyjet Matrix Technology, the 260 Connex can simultaneously build 14 different materials into a single model part, providing a highly detailed and accurate depiction of the final product. With choice of over

60 different build materials, the possibilities are endless to what we can create. A typical Objet 260 Connex Polyjet 3D Printing Machine is illustrated in figure.1. Complete specifications of the same 3D printer are given in table.2.

Figure 1. Objet 260 Connex Polyjet 3D Printer

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2.3 Verowhite board preparation

Table 2. Specifications of Object Connex 260 Polyjet Printer

Maximum materials per part	82
Maximum build size (XYZ)	255 × 252 × 200 mm
Minimum layer thickness	Horizontal build layers as fine as 16 microns
Build modes	Digital material (30 micron resolution), High quality (16 micron resolution) and High speed (30 micron resolution)
Finishes	Glossy finish (Smooth surface) Matte finish (Rough surface)
Software	Objet Studio Intuitive 3D Printing Software
Operating conditions	Temperature (18 - 25° C) & Relative humidity (30-70%) System size and weight 87 × 120 × 73.5 cm and 264 kg
Power requirements	110 - 240 VAC 50/60 Hz, 1.5kW Single phase

Appropriate amount of verowhite material is filled in the form of liquid stage inside the Object Connex 260 Polyjet 3D Printer. Initially adequate input and output parameters were feeded in the Objet Studio Intuitive 3D Printing Software. Verowhite board was prepared by executing the print mode command in the 3D printer. Four different modes were selected and executed to produce the four different verowhite boards for mechanical properties evaluation.

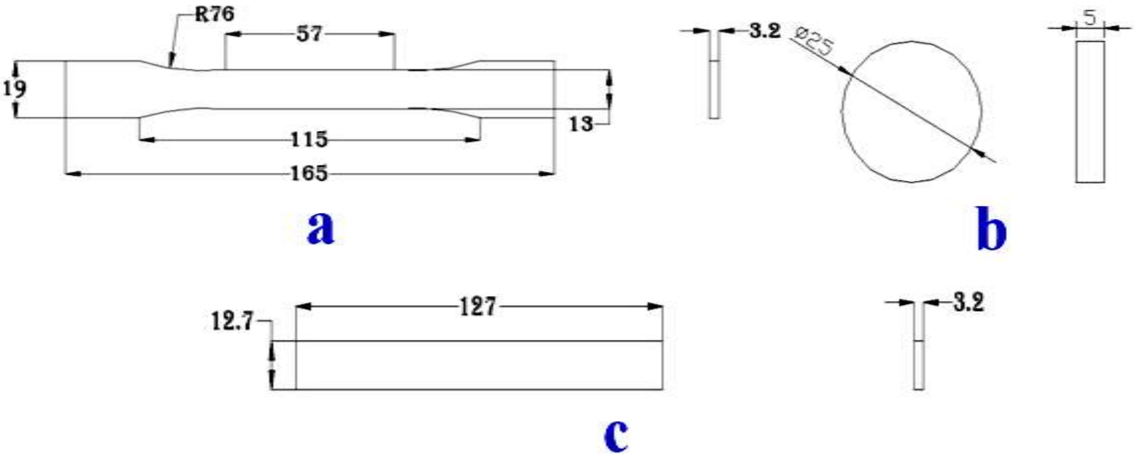

Figure 2. Test specimen's standards (a) Tensile test -ASTM D638 (b) Shore hardness – ASTM D2240 (c) Flexural test-ASTM D790.

2.4 Verowhite specimen's preparation

The well prepared verowhite boards are taken away from the 3D printer are then allowed to cool from its build temperature into room temperature. Post processing cleaning process is carried out on the 3D printed verowhite specimen board and well cleaned boards are named and categorized as shown in table.3 for further mechanical tests. Standard water jet

ISSN- 2394-5125 VOL 7, ISSUE 04, 2020

machining processes were adopted to prepare the test specimens as per the ASTM standards. Test specimens which are prepared as per ASTM standard for tensile, shore hardness and flexural test were shown in figure.2. 3D printed verowhite specimens as per ASTM before the tensile test, flexural test, shore hardness test and roughness test were represented in figure.3
(a), (b), (e) and (f) respectively.

2.5 Mechanical tests

The tensile test was performed on the four different print mode verowhite specimens with the help of digitalized Universal Testing Machine (UTM), which is shown in figure.3 (g). Test specimens after tensile test are shown in figure.3 (c).

Corresponding tensile properties of the specimens were observed, tabulated and discussed in results and discussions chapter of this work. After the successful completion of the tensile test, flexural test was carried out on the flexural test specimens of verowhite materials by using the same Universal Testing Machine (UTM). Different flexural properties were observed for all verowhite flexural specimens. Flexural test specimen after test is illustrated in figure.3 (d). Top and bottom surface shore hardness evaluation for verowhite specimens were performed in shore hardness tester. Experimental results were noted and observed for all specimens. Surface roughness tester was used to establish the surface hardness of the all verowhite specimens. Values for surface roughness of the four different printed modes were observed through surface roughness tester.

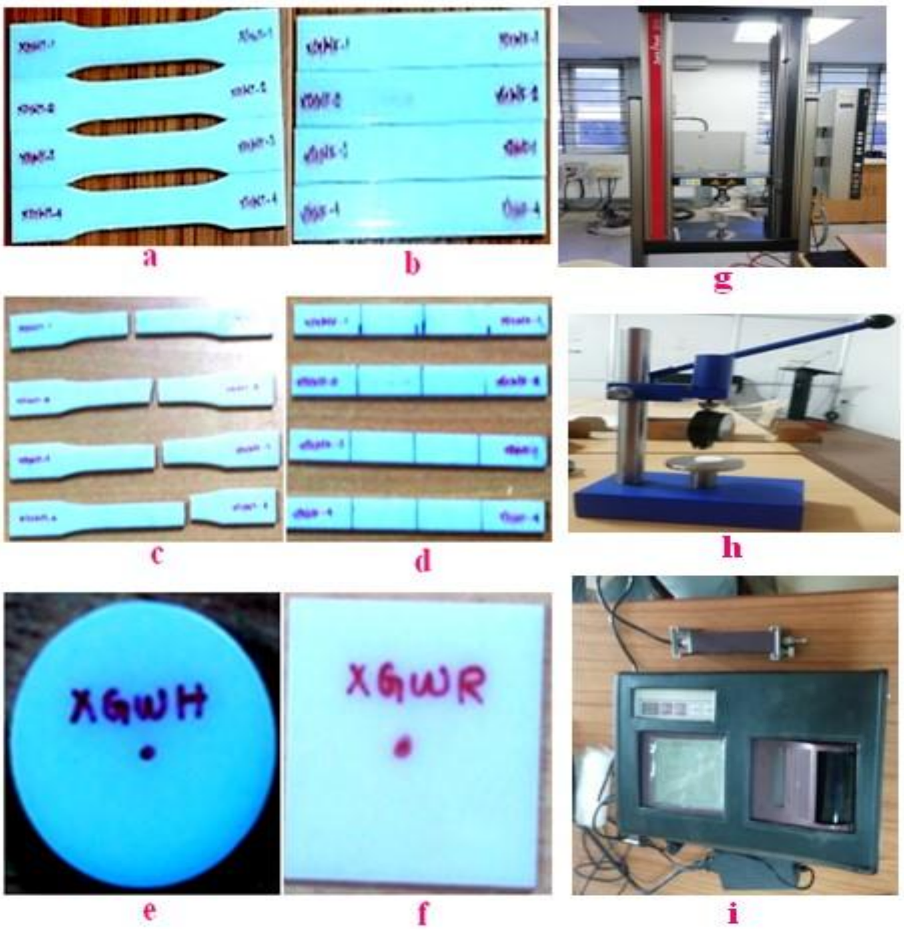

Figure 3 (a) Tensile test specimens before test (b) Flexural test specimen before test (c) Tensile test specimens after test (d) Flexural test specimen after test (e) Hardness test specimen (f) Roughness test specimen (g) Universal Testing Machine (UTM) (h) Shore hardness testing machine (i) Surface roughness testing machine

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Table 3. Specimen description

	name	Test specimen description
1.	XGWT	High quality glossy finished Verowhite tensile test specimen
2	XMWT	High quality matte finished Verowhite tensile test specimen
3	YGWT	High speed glossy finished Verowhite tensile test specimen
4	YMWT	High speed matte finished Verowhite tensile test specimen
5	XGWF	High quality glossy finished Verowhite flexural test specimen
6	XMWF	High quality matte finished Verowhite flexural test specimen
7	YGWF	High speed glossy finished Verowhite flexural test specimen
8	YMWF	High speed matte finished Verowhite flexural test specimen
9	XGWH	High quality glossy finished Verowhite hardness test specimen
10	XMWH	High quality matte finished Verowhite hardness test specimen
11	YGWH	High speed glossy finished Verowhite hardness test specimen
12	YMWH	High speed matte finished Verowhite hardness test specimen
13	XGWR	High quality glossy finished Verowhite roughness test specimen
14	XMWR	High quality matte finished Verowhite roughness test specimen
15	YGWR	High speed glossy finished Verowhite roughness test specimen
16	YMWR	High speed matte finished Verowhite roughness test specimen

3. Results and discussions

The following results were acquired from the different mechanical tests on the four different 3D printed mode Verowhite material specimens. Variation on yield strength and tensile strength of the specimens are illustrated in figure.4 respectively. Yield strength of the specimen's are found maximum in high speed glossy finished print mode specimens in addition to that the minimum strength of the specimens at yield point was identified in high quality glossy finished print mode specimens respectively. Tensile strength of the Verowhite specimens during the tensile test is observed maximum in high speed glossy finished and high quality glossy finished print mode correspondingly. Effect of different printing mode on Verowhite specimens for tensile and secant modulus were depicted in figure.5. It was noted that the maximum and minimum tensile modulus and secant modulus is obtained in high speed glossy finished and high quality glossy finished print mode specimens. Tensile modulus during the beginning and ending of the tensile test is represented in figure.6. Maximum and minimum value of beginning tensile modulus was found in high quality glossy finished and high speed matte finished print mode specimens respectively.

Tensile modulus during end of the tensile test was found maximum and minimum in high speed glossy finished print mode and high quality glossy finished print mode specimens correspondingly. Stress exposed by the Verowhite specimens during the tensile test at break and the percentage of elongation is demonstrated in figure.7. It is noticed that the Verowhite specimen printed in high speed glossy finished print mode expose the maximum stress during the break. Minimum stress observed by the specimens during break was found in high quality glossy finished print mode Verowhite material respectively. Stresses released during the tensile test at 1% elongation, yield strain and elongation tensile strength of the all print mode specimens were shown in figure.8. It shows that the minimum and maximum of stress at 1% of elongation during the tensile test was found in high speed matte finished print mode specimens. Yield strain obtained by the specimens was found maximum and minimum in high quality glossy finished print mode specimens. Percentage of elongation tensile strength during the tensile test was found maximum and minimum in high speed matte finished print mode and nigh quality matte finished matte print mode specimens correspondingly. Variation of flexural modulus and secant modulus for all mode printed Verowhite specimens were shown in figure.9. It is observed that the Verowhite specimen printed in high quality glossy print mode exposed maximum flexural modulus than other printed mode specimens. Minimum flexural modulus during the flexural test was found in high speed matte finished print mode specimens. Maximum and minimum secant modulus is recognized in high quality glossy print mode and high speed matte finished print mode specimens accordingly. Flexural modulus at 0.1% during plastic deformation, flexural stress at 1% and 2 % plastic deformation were highlighted in figure.10. Flexural modulus at 0.1% plastic deformation of the Verowhite specimen was established minimum and maximum in high quality glossy print mode and high speed matte finished print mode specimens respectively. Maximum and minimum stress released by the Verowhite specimen during the plastic deformation at 1% and 2 % is discovered in high quality glossy print mode and high speed matte finished print mode specimens notably. Variation on flexural strength for verowhite specimens were illustrated in figure.11. Strength exhibited by the all mode printed Verowhite specimens during the flexural strength (flexural

ISSN- 2394-5125 VOL 7, ISSUE 04, 2020

strength) were found maximum and minimum in high quality glossy print mode and high speed matte finished print mode specimens obviously. Top side and bottom side shore hardness results were obtained for all modes printed specimens from shore hardness tester were illustrated in figure.12 & 13 respectively. The top side shore hardness was attained maximum and minimum in high quality glossy and high quality matte finished mode printed specimens respectively.

High quality glossy finished and high speed glossy finished Verowhite specimen's exhibits the maximum and minimum bottom shore hardness respectively. Variation on surface roughness for Verowhite specimens were depicted in figure.14. High speed matte finished and high quality glossy finished print mode specimens are exhibits the maximum and minimum arithmetic average top surface roughness than other mode printed specimens. Arithmetic average bottom surface roughness was observed maximum in High speed glossy finished and minimum in high quality matte finished printed mode specimens. Ten points mean top surface roughness of the Verowhite specimens were found maximum and minimum in high speed matte finished and high speed glossy finished print mode extensively. Verowhite specimens which is printed by high speed glossy finished mode and high quality matte finished mode are reveals the maximum and minimum of ten points mean bottom surface roughness evidently.

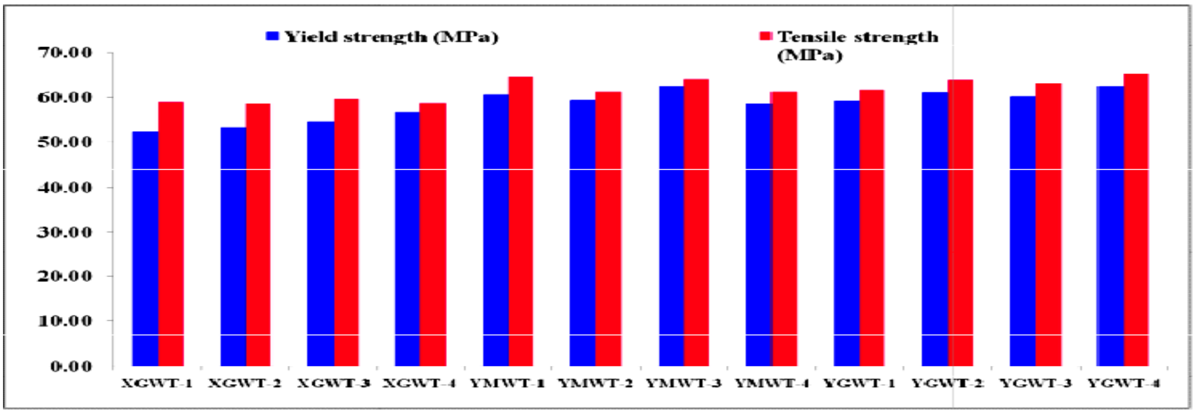

Figure 4. Variation of yield strength and tensile strength for different Verowhite specimens

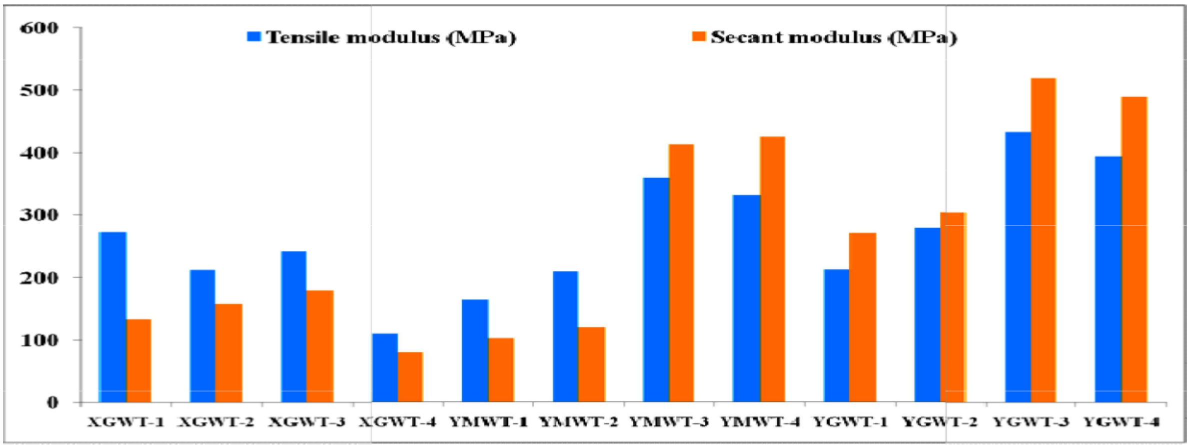

Figure 5. Variation of tensile modulus and secant modulus for different Verowhite specimens

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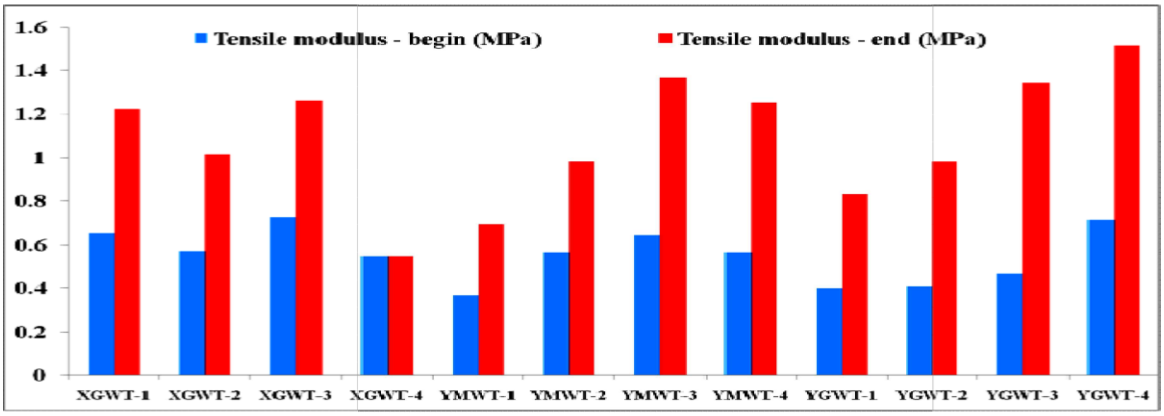

Figure 6. Variation on tensile modulus of Verowhite specimens during tensile test beginning and end

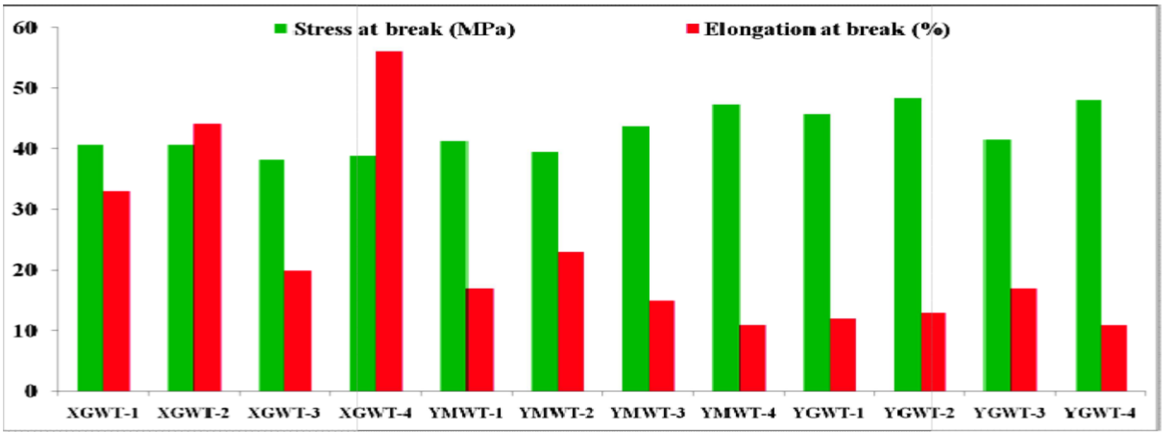

Figure 7. Variation on stress and elongation percentage of Verowhite specimens during break

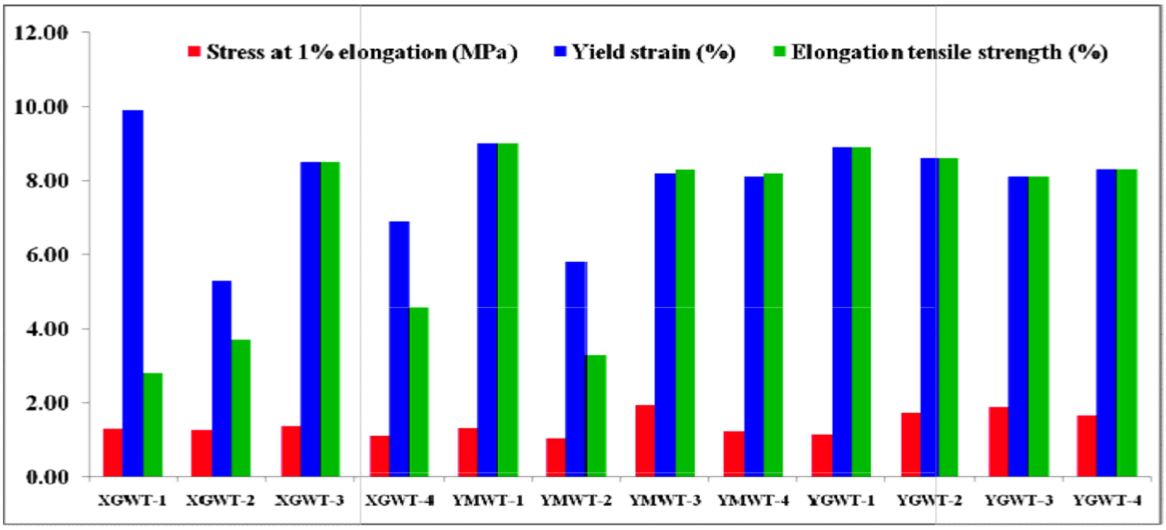

Figure 8. Variation on 1% elongation, yield strain and percentage of elongation tensile strength of Verowhite specimens

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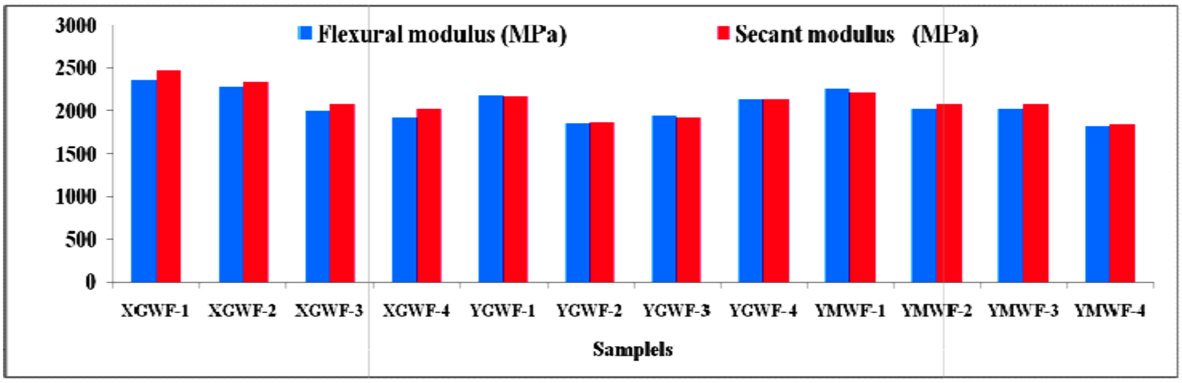

Figure 9. Variation of flexural strength and Secant modulus for different Verowhite specimens

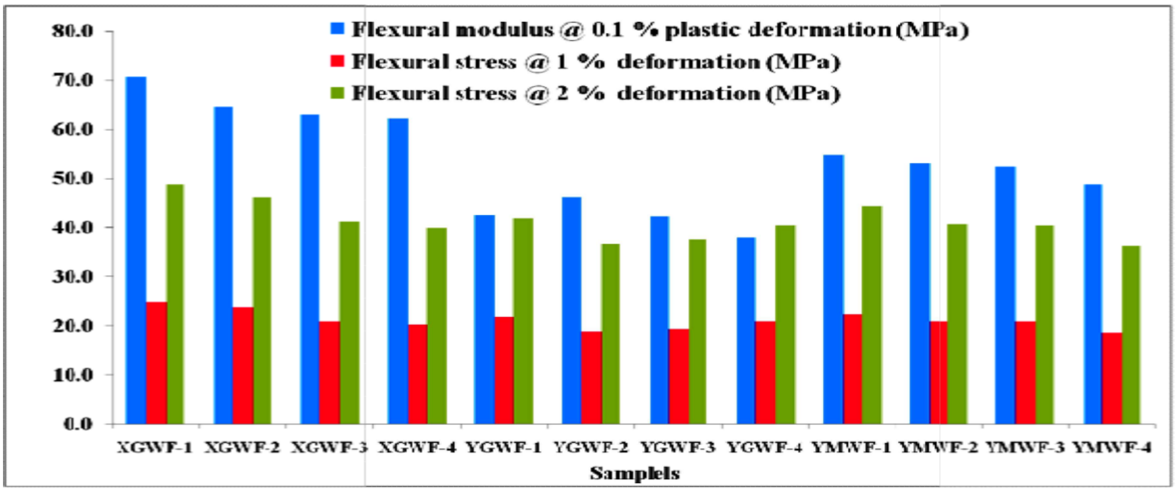

Figure 10. Variation of flexural stress at 0.1%, 1% and 2% of plastic deformation for different Verowhite specimens

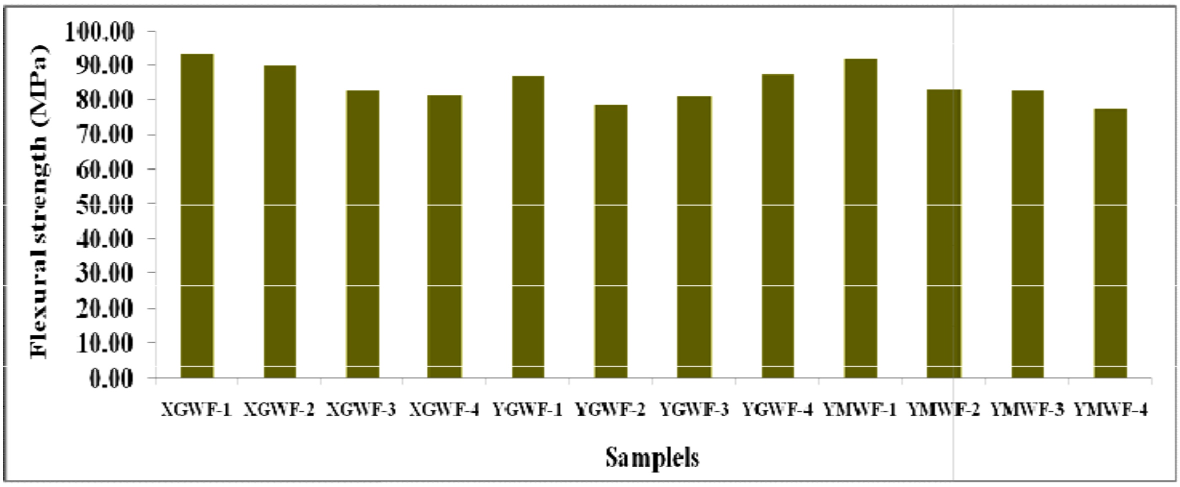

Figure 11. Variation of flexural strength for different Verowhite specimens

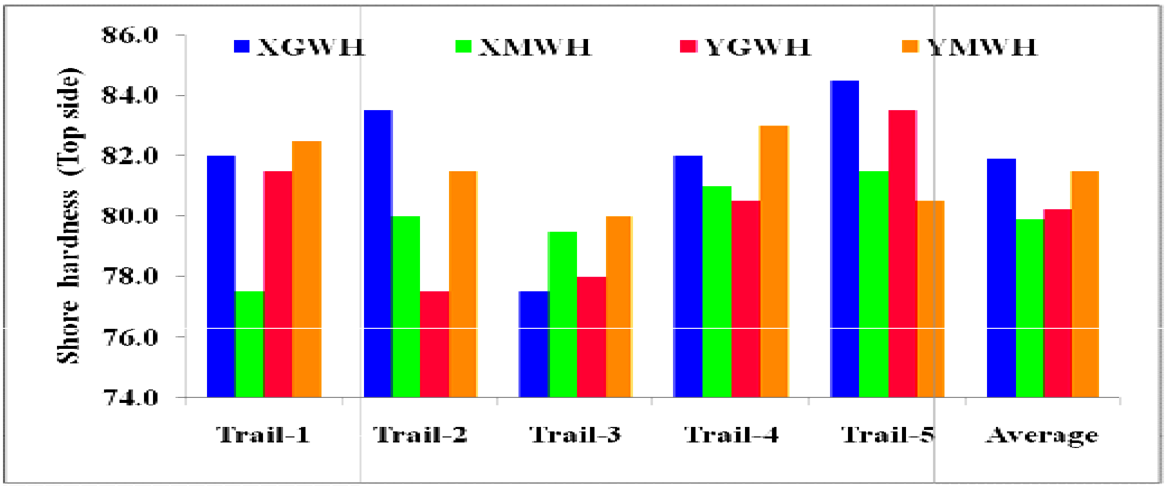

Figure 12. Variation on top side shore hardness of Verowhite specimens

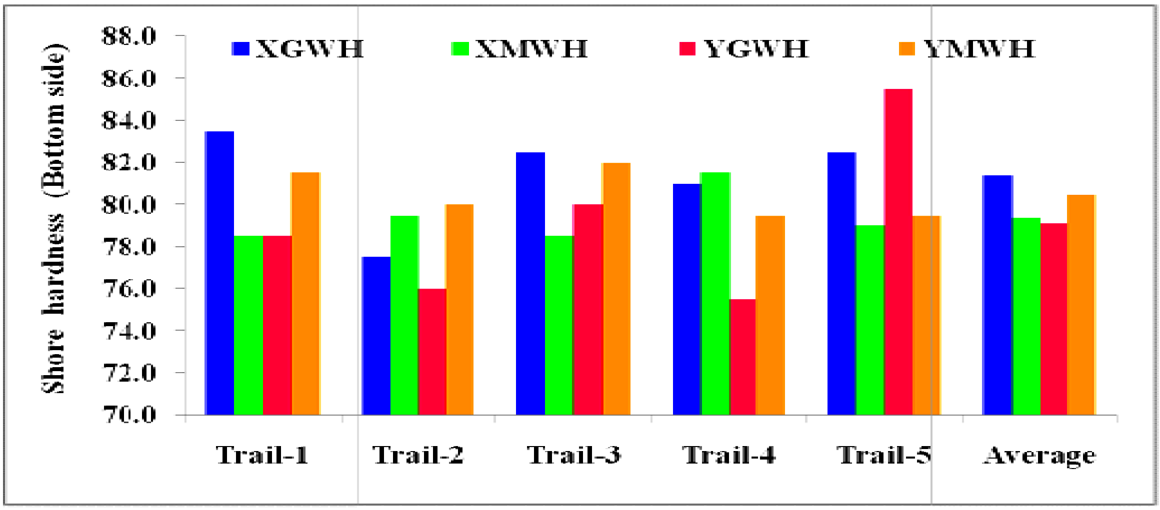

Figure 13. Variation on bottom side shore hardness of Verowhite specimens

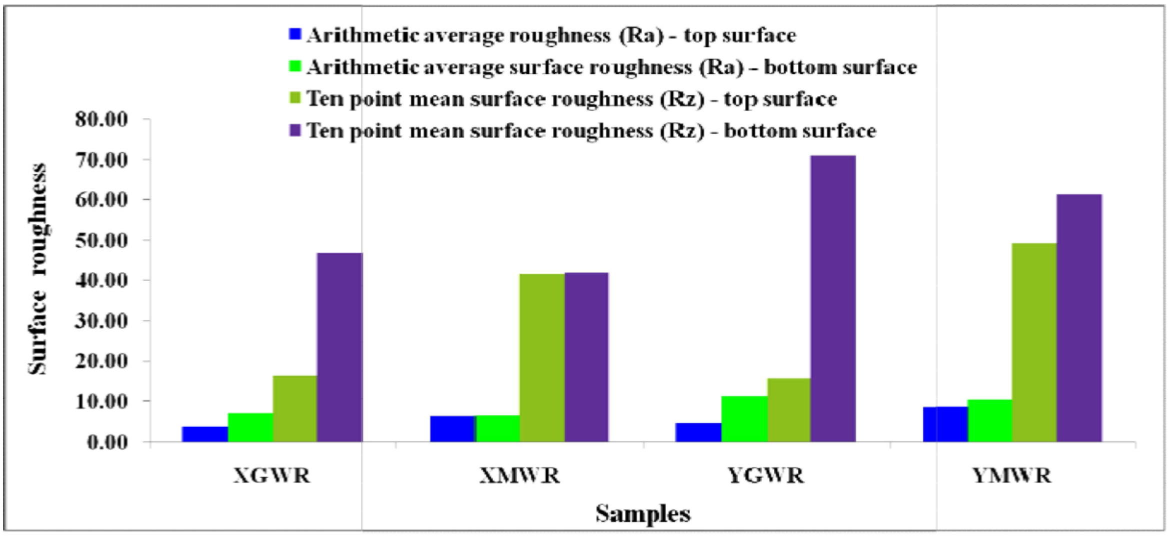

Figure 14. Variation on surface roughness of Verowhite specimens

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4. Conclusions

In this research work, the state of the art of an Object 260 Connex Polyjet 3D printing machine printed Verowhite specimens with four different printing methods are represented and the following mechanical performance of that specimen were established and compared with each other. Maximum tensile strength (65.2 MPa) and minimum tensile strength (58.6) of the Verowhite specimens were exposed in high speed glossy finished and high quality glossy finished print mode respectively. Yield strength of the specimens is acknowledged maximum (62.31 MPa) in high speed glossy finished print mode specimens. Likewise, minimum yield strength of 52.31 MPa was obtained in high quality glossy finished print mode specimens. Percentage of elongation during breaking was found maximum (56%) and minimum (11%) in high quality glossy finished and high speed matte finished print mode specimens correspondingly. Printed Verowhite specimens with high quality glossy finished mode in a Polyjet 3D printer reveal the better flexural properties than other three printing modes. The average flexural strength and flexural modulus of 86.65 MPa and 2145 MPa were found in high quality glossy finished mode Verowhite specimens. The maximum and minimum shore hardness (81.9 & 79.9) of the specimen's top side was noticed in high quality glossy and high quality matte finished mode printed specimens respectively. High quality glossy finished and high speed glossy finished Verowhite specimen's exhibits the maximum and minimum bottom shore hardness (81.4 & 79.1) respectively. Arithmetic average top surface roughness of the specimens were found maximum (8.43) in high speed matte finished and minimum (3.52) in high quality glossy finished print mode specimens considerably. High speed glossy finished and high quality matte finished printed mode specimens were shows the maximum (11.19) and minimum (6.63) arithmetic average bottom surface roughness appreciably. Ten points mean top surface roughness of the Verowhite specimens were found maximum (49.23) and minimum (15.64) in high speed matte finished and high speed glossy finished print mode significantly. Verowhite specimens which is printed by high speed glossy finished mode and high quality matte finished mode are reveals the maximum (71.09) and minimum (41.98) of ten points mean bottom surface roughness noticeably. Experimental studies exposed that the mechanical properties of Verowhite material were superior in high quality glossy finished print mode specimens.

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