EFFECT OF INCORPORATION OF SILVER NANOPARTICLES ON TENSILE STRENGTH AND IMPACT STRENGTH OF POLY (METHYL METHACRYLATE) ACRYLIC RESIN-AN INVITRO STUDY.

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ABSTRACT

Statement of problem: An ideal denture base material is that which possesses biocompatibility with the oral tissues, excellent esthetics and superior mechanical properties. Clinical failures of complete or partial denture prosthesis caused from poly methyl methacrylate are most likely in the form of fracture either due to fatigue or impact forces of mastication.

Purpose: To evaluate the tensile strength and impact strength of poly methyl methacrylate(PMMA) reinforced with silver nanoparticles

Material and methods: For tensile and impact strength tests a total of 70 heat cure acrylic specimens were fabricated with dimension 60x20x2mm in length, breadth and thickness respectively. The specimens were divided into two groups, in which 35 were unmodified PMMA samples and 35 were modified PMMA with silver Nano particles.

The tensile and impact strength were evaluated using universal testing machine. The data was subjected to Independent sample t-test and results were obtained.

Results: The strength test of acrylic samples for impact test group were statistically significant ($p<0.05$). The strength test of acrylic samples for tensile test group were statistically insignificant ($p>0.05$).

Conclusion: Within the limitation of this study, it was concluded that the tensile strength of the acrylic resin did not vary much with the addition of silver nanoparticles and it was statistically insignificant. The impact strength of the acrylic resin significantly reduced with the addition of silver nanoparticles.

Clinical implications: A frequent problem in dental prostheses is fracture, which may be caused by accidental falls, repeated masticatory forces, and stress concentration areas. For this reason, the physical and mechanical properties of polymers used to make prostheses is of significant importance in predicting their clinical performance.

INTRODUCTION

Edentulism is a matter of great concern to a majority of population and the necessity of replacement by artificial substitutes such as dentures fabricated with acrylic resin is vital for leading good quality of life. Denture base acts as an intermediary between teeth and the jaw and has to transmit all or part of the masticatory forces to the underlying tissues. One of the most common problems confronted in the provision of such prosthesis is whether the constraints of strength and design meet the functional requirements of the oral cavity.Artificial substitutes in the oral cavity require superior esthetic, adequate strength, low water sorption and low solubility and good biocompatibility with the sub-adjacent tissues which is inherent in acrylic resins. Acrylic resin reproduces minute and accurate surface details and they can be easily repaired when damaged. However, there are a few drawbacks of acrylic resin which during processing leads to dimensional inaccuracy and comparatively low modulus of elasticity which causes its rapid deformation at low stresses due it certain properties such as low thermal conductivity and high co-efficient of thermal expansion.[1]

Dootz et al conducted a study and noted that impact failure extra orally and flexure fatigue failure intraorally are the two most important causes of fracture of denture base.[2] The physical and mechanical properties can also be improved by addition of carbon fibres, polyethylene fibers and metal fillers such as silver and aluminium powder. The thermal conductivity, polymerisation shrinkage can be improved while adding silver, copper and/or aluminium in the form of microparticles (powder) to the resin.[3]

Several studies have shown that when silver nanoparticles are added to acrylic resin they exhibit antimicrobial behavior. Chladek et al reported that Candida albicans, one of the most common pathogen in the oral cavity can be restricted by adding silver nanoparticles to acrylic resin. The antimicrobial activity again Candida albicans is noticeable when silver is used as nanoparticles.[4]

Inorganic nanoparticles exhibiting novel and improved physical, chemical, biological properties and functionality due to their nanoscale size have gained much importance over the past few decades. Silver particles have been incorporated to PMMA to enhance its mechanical properties. Micrometer size articles were commonly used some years back, but they presented with several drawbacks. Further researches on nanotechnology sciences, nanoparticles were added to PMMA which led to better processing and good quality of the resin. Among the nanoparticles silver gained much of importance due to its well-tolerated tissue response and low toxicity profile. With the advent of nanotechnology into medical fields such as central venous catheter, orthopaedic metallic rods and grafting materials they have gained much of demand in the market. The Nano sized particles provide better antimicrobial activity than the micrometer-sized particles.[5-8]

Conclusive studies on properties of acrylic resin on incorporation of silver nanoparticles have not been reported to date. This study will evaluate the acrylic resin on properties such as impact and tensile strength. This study aims to assess these parameters.

MATERIALS AND METHODS

For the purpose of this study, colloidal silver nanoparticles of size 10-20nm were used. The concentration of the silver nanoparticles used in this study is 50ppm (0.005%).

For impact and tensile strength tests the acrylic specimens with dimension of 60×20×2mm were fabricated. The Custom made metallic mould was fabricated according to ASTM D638-10 (ISO 527)[3] which consisted of an upper and lower member. The intermediate member consisted of 5 rectangular mould spaces of dimension 60x20x2mm.This mould space was placed between the upper and lower member (Fig 1).

A total of one hundred and forty rectangular heat cure acrylic resin samples were fabricated out of which seventy specimens were incorporated with 0.005% silver nanoparticles. The remaining seventy samples were unmodified acrylic resin, which acted as control group. The specimens were divided into 4 groups. 35 samples each of unmodified resin was used as control group for tensile and impact strength test. 35 samples each of modified resin with silver nanoparticles were used as test group for evaluating tensile and impact strength.

For the preparation of the acrylic specimens, petroleum jelly was applied into the mould. Conventional heat processed polymethyl methacrylate denture base resin was mixed in a porcelain jar according to manufacturer's recommended ratio (24g polymer to 10 ml of monomer). 0.8ml of colloidal nanosilver was added to 10 ml of monomer[21]. The resin was left in the mixing jar until it reached the dough stage, then the mix was kneaded thoroughly to a homogenous dough and was subsequently packed in the mould space. The upper member was placed over the mould space. The metallic mould was closed properly under 2 MPa pressure in a bench press and bench cured for 60 minutes at room temperature[22]. It was then polymerized using the conventional compression moulding technique. The metallic mould with clamp was kept in a temperature controlled acrylizer and processing was carried out using the rapid curing cycle at 74 degrees centigrade for two hours followed by boiling at 100 degrees centigrade for one hour. After the curing cycle was completed, the metallic mould was bench cooled to room temperature before retrieval of the specimens. The test specimens were carefully retrieved from the moulds.

All specimen surfaces were trimmed using fine grade tungsten carbide bur. The surface roughness was smoothened using 120 grit sand paper (ARPEE’S PHOENIX products) and each specimen was polished using a rag wheel and a feld cone with pumice slurry for 15 seconds at the rate of 2800 rpm. Prior to the tensile and impact strength tests. The specimens were stored in 37˚C distilled water for 50 hours to simulate the oral environment[21].

The samples were grouped into four groups as follows:

Group A – Control group for tensile strength.

Group B – Test group for tensile strength.

Group C – Control group for impact strength.

Group D – Test group for impact strength.

Testing for tensile strength:

The tensile strength was measured using Universal testing machine (computerized, software based) ACME engineers, India.Model No. UNITEST-10. The Cell load capacity was 20Kn and the cross head speed for the test was 5mm/minute. The test rig consisted of a loading wedge and a pair of supporting wedges placed 40 mm apart which represents the average intermolar distance of a denture[23]. Each test specimen was placed on the testing rig so that the loading wedge, set to move apart at a speed of 5 mm/min, engaged the right and left edges of the specimen until the specimen broke. In other words, the specimens were loaded until fracture occurred (Fig 2).

The peak load recorded was converted to tensile strength by using the formula.

$$\text{Tensile strength} = \frac{\text{Force}}{\text{Area}}$$

Tensile strength= stress measured in Nm^{-2} or Pascal (Pa)

F = force in Newton (N)

A = cross-sectional area in mm^2

Testing for Impact strength:

The Impact strength was measured using Izod/Charpy Impact Tester (computerized, software based). The sample was placed in a metal fixture so that the middle of the sample coincided with the striking pendulum. The 2 J pendulum struck the sample until fracture of the material wasobtained (Fig 3).

The energy required to break the sample was measured in Joules and noted. Thus, the Impact strength was calculated using following formula

$$I_s = \frac{E}{hp}$$

Where,

I_s =Impact strength (in MPa).

h = Thickness of specimen in mm (2 mm).

p = Width of specimen (20 mm).

RESULTS

The data obtained during the course of the study was entered in Microsoft Excel Spreadsheet. The data was first subjected to descriptive statistics namely mean and standarddeviation. Foralltheanalysis,apvalueof< 0.05 was considered to be statistically significant. Comparison of tensile and impact strength between the control and test group was done using the Independent Sample T-test.

Evaluation of Tensile strength:

Independence sample t-test showed no significant difference in the mean tensile strength between Group A (41.85) and Group B (44.16). The standard deviation between the two groups has been presented in table 1.Mean distribution of the samples based on tensile strength is illustrated in figure 4.

It was observed that there was no statistically significant difference in the mean value between the control and test group (Table 3). The p- value was 0.22 revealed there was no statistically significant difference. It means that the tensile strength did not vary much with the addition of silver nanoparticles.

Evaluation of Impact strength:

Group C showed highest mean impact strength of 638 J/m as compared to Group D which showed 453.71 J/m. The standard deviation between two groups is presented in Table 2. Mean distribution of the samples based on impact strength is illustrated in figure 5.

It was observed that there was statistically significant difference in the mean value between control and test groups (P=0.04) with respect to impact strength (Table 3). It means that the impact strength significantly reduced with the addition of silver nanoparticles.

DISCUSSION

This in-vitro study was aimed to investigate the tensile strength and impact strength of heat cured acrylic PMMA specimens reinforced with 0.005% of silver Nano particles. The two test groups of specimens were tested for Tensile Strength and Impact Strength using a Universal Testing Machine.

Poly methyl methacrylate is one of the most commonly used material in the fabrication of dental prosthesis. PMMA is not ideal in every aspect but it is the combination of various properties rather than a single desirable property that accounts for its popularity and usage. Despite its popularity in satisfying aesthetic requirements whereby, with an appropriate degree of clinical expertise and with the careful selection and arrangement of artificial acrylic teeth, it is possible to produce a prosthesis which defies detection, it is still far from ideal in fulfilling the mechanical requirements of a prosthesis.[11]

Several researchers have demonstrated that PMMA can show good fatigue behaviour and impact strength when it is reinforced by carbon fibers.[24-26] The incorporation of silver, copper, and/or aluminium in the form of powder into the resin was found to improve its mechanical properties.[27, 28] Regarding the increasing advancements in nanotechnology in terms of adding Nano silver particles to an acrylic base, the use of Nano silver particles has been preferred to silver powder because the nanoparticles cause better processing and smoother surfaces than the silver powder.[29]

Fractures in dentures result from two different types of forces, namely, flexural fatigue and impact failure. This type of failure can be explained by the development of microscopic cracks in areas of stress concentration. With continued loading, these cracks fuse to an ever-growing fissure that insidiously weakens the material. Catastrophic failure results from a final loading cycle that exceeds the mechanical capacity of the remaining sound portion of the material The midline fracture in a denture is often a result of flexural fatigue. Impact failures usually occur out of the mouth as a result of a sudden blow to the denture or accidental dropping whilst cleaning, coughing or sneezing.[11]

In the present study the size of the silver Nano particles was 50 nm. Koroglu et al. stated that smaller nanoparticles are more effective against bacteria.[30] However, when the silver nanoparticle dimensions are less than 3 nm, they are more cytotoxic than larger particles (25 nm).[31] The concentration of silver Nano particles used in this study is 0.005% which used as a modifier to PMMA, since the results of the previous studies showed, low concentrations Silver nanoparticles have no negative effects on the mechanical properties of PMMA. In addition, high concentrations of nanoparticles produce agglomeration sites that adversely affect the material's properties

Three approaches have been developed for the preparation of nanocomposites: (1) mixing nanoparticles with the polymer, (2) adding nanoparticles to the monomer, (3) generating nanoparticles during polymerization. In the current study, to reduce the agglomeration and to readily achieve polymer/silver nanocomposites, the Silver nanoparticles was dispersed in liquid (monomer) and then mixed with the powder (polymer) of the acrylic material.[20]

Chladek et al reported that the mechanical and physical properties of the composite are influenced by silver nanoparticle concentration. They also showed that mechanical properties of composites decreased by increasing silver nanoparticles. It has been demonstrated that addition of more than 5 wt% of the metal fillers into acrylic resin would reduce tensile strength.[4]

A tensile stress is caused by a load that tends to stretch or elongate a body. A tensile stress is always accompanied by tensile strain.[32] In the current study, tensile strength of the modified PMMA with 0.005% was found to be 44.16 and unmodified PMMA was 41.85. There was no statistically significant difference between the two groups. The results also demonstrated that the tensile strength did not vary much with the addition of 0.005%silver nanoparticle. A statistical significant result could be achieved if the sample size was increased in future studies.

A frequent problem in dental prostheses is fracture, which may be caused by accidental falls, repeated masticatory forces, and stress concentration areas. For this reason, the impact strength of polymers used to make prostheses is of significant importance in predicting their clinical performance.Multiple methodologies have been described to evaluate this parameter, with notched specimensand unnotched specimensbeing used to assess strong impact points. However, as a notch may weaken the material and the same come to fracture at low tension and be a difficult, time-consuming, and irreproducible method,unnotched specimens were chosen for this study.[19]In this study all the impact specimens broke with a sharp fracture. This type of fracture is typical of brittle fracture behaviour characterized by the lack of distortion of the broken parts.

The addition of 0.005% significantly decreased the impact strength of resins when compared with the control group. This result can be attributed to difficulty in homogenizing nanoparticles in the polymeric matrix. Nanocomposite clusters which may be formed in the process act as stress centres, weakening the system.

Nanoparticles are easy to incorporate into the monomer-polymer mixture. Against this the incorporation of fibers-glass, aramid, polyethylene, etc are difficult to place accurately and complex as they shift under pressure, making it labor intensive.[33] Unlike fibers, planar reinforcements in nanomaterials is not possible. If such reinforcements are arranged parallel to their principal plane in a composite material, they thus provide a distinctly higher performance than fiber reinforcements for two-dimensional loading conditions. This higher performance amounts to about a factor three for the Young's modulus and a factor two for the tensile strength. However, in spite of this obvious advantage, composites with planar reinforcements are as yet relatively unknown. This is mainly due to the fact that planar reinforcements are not as readily available as fiber reinforcements and therefore not much work has been done on this aspect.

Various suggestions have been made to improve the interface between the denture base material and the reinforcing material, such as silanization, plasma treatment, etc.[11, 34] These modes of improvement applied to nanoparticles can further improve the properties of the obtained reinforced acrylic matrix.

CONCLUSION

This study was conducted using 140 acrylic specimens which were divided into four groups. 70 specimens were unmodified PMMA which acted as control group and the remaining specimens were modified with silver Nano particles which acted as the test group.

The specimens were prepared as per ADA specification number 12. The tensile strength and impact strength were tested. Within the limitations of the study it was concluded that the tensile strength test was statistically insignificant. It means that the tensile strength did not vary much with the addition of silver nanoparticles in the test group. The silver nanoparticle reinforced group yielded lower impact strength than the control group. The change in the impact strength was significant at individual group level.

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Figure 1

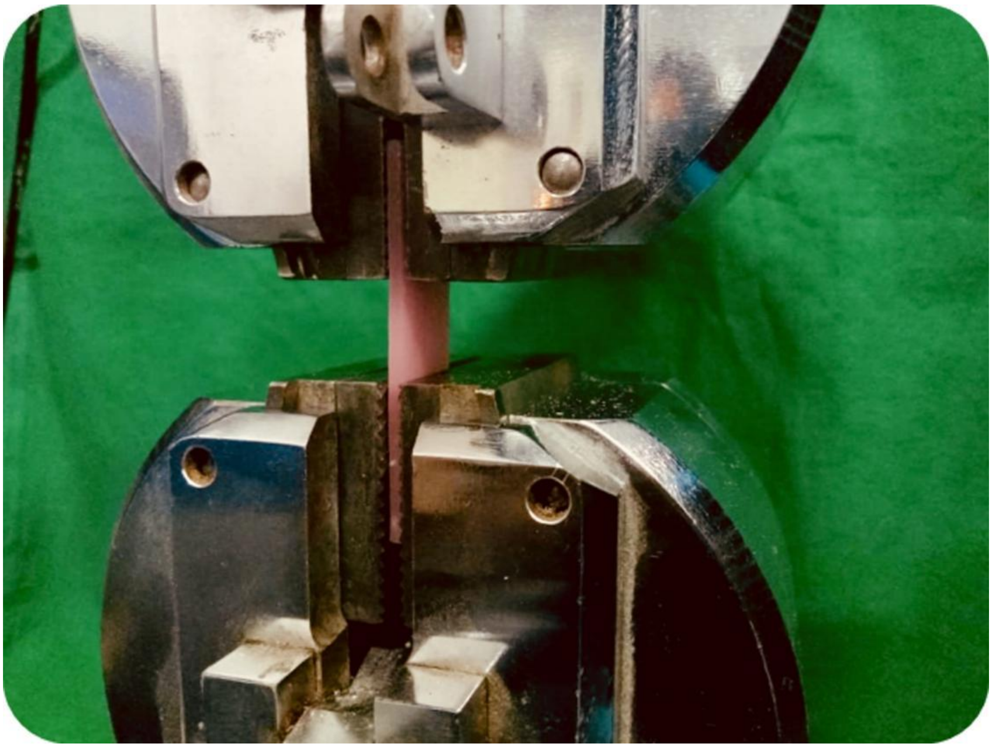

Figure 2

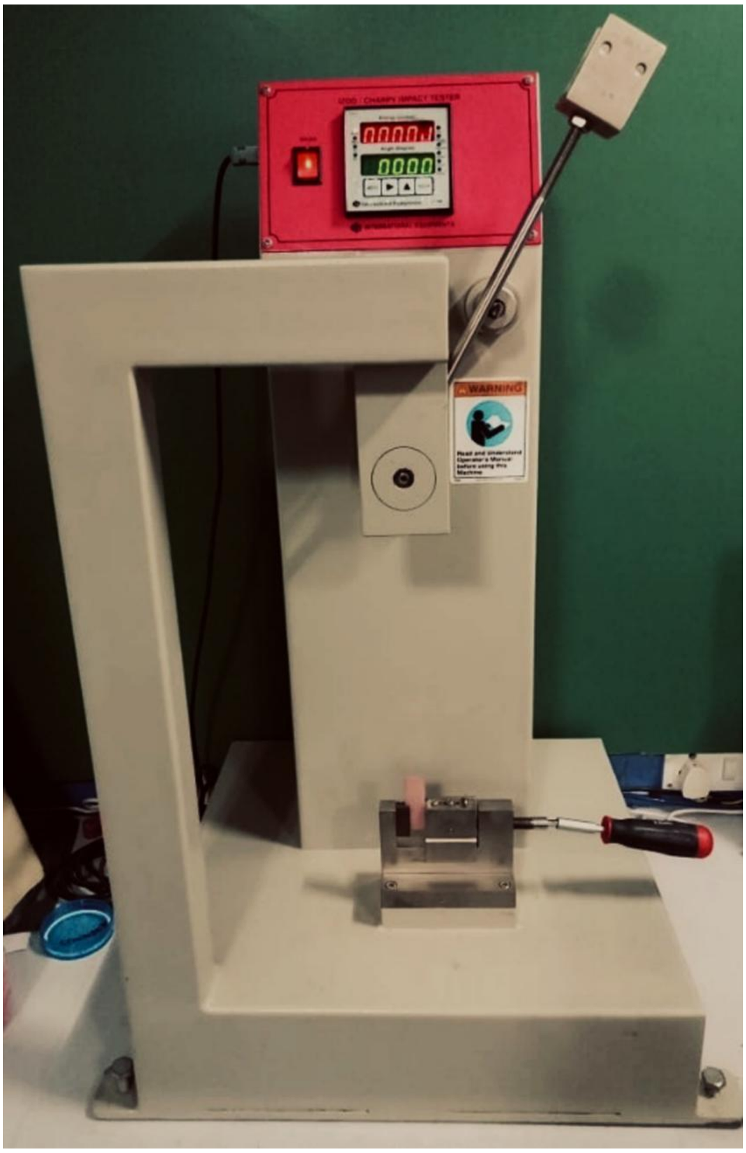

Figure 3

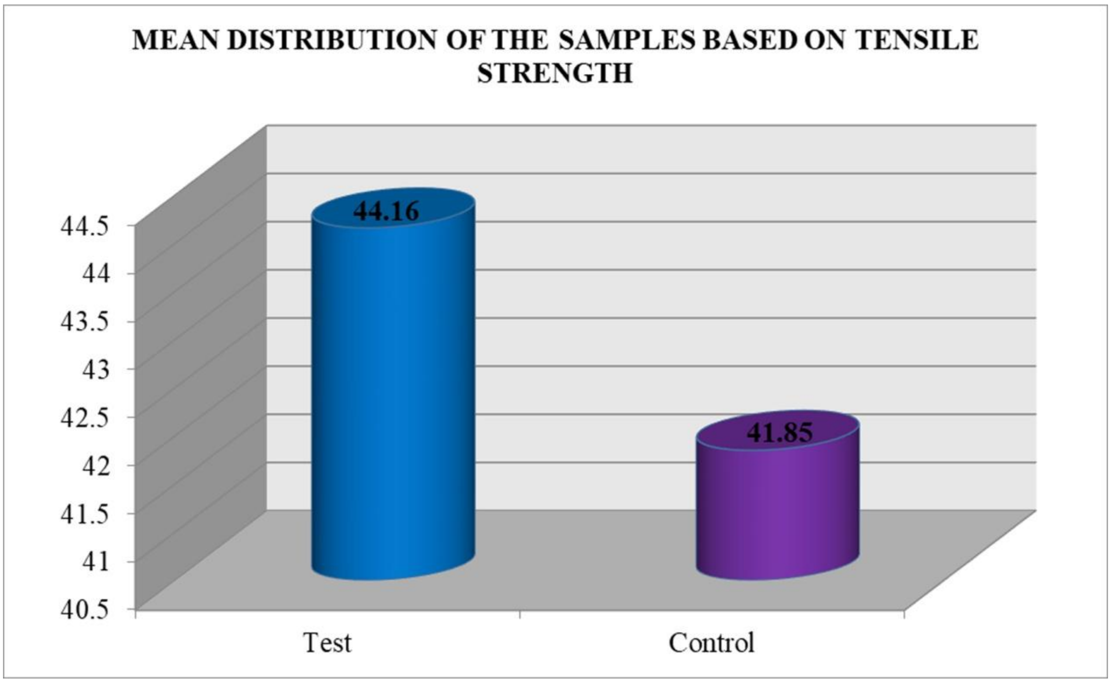

Figure 4

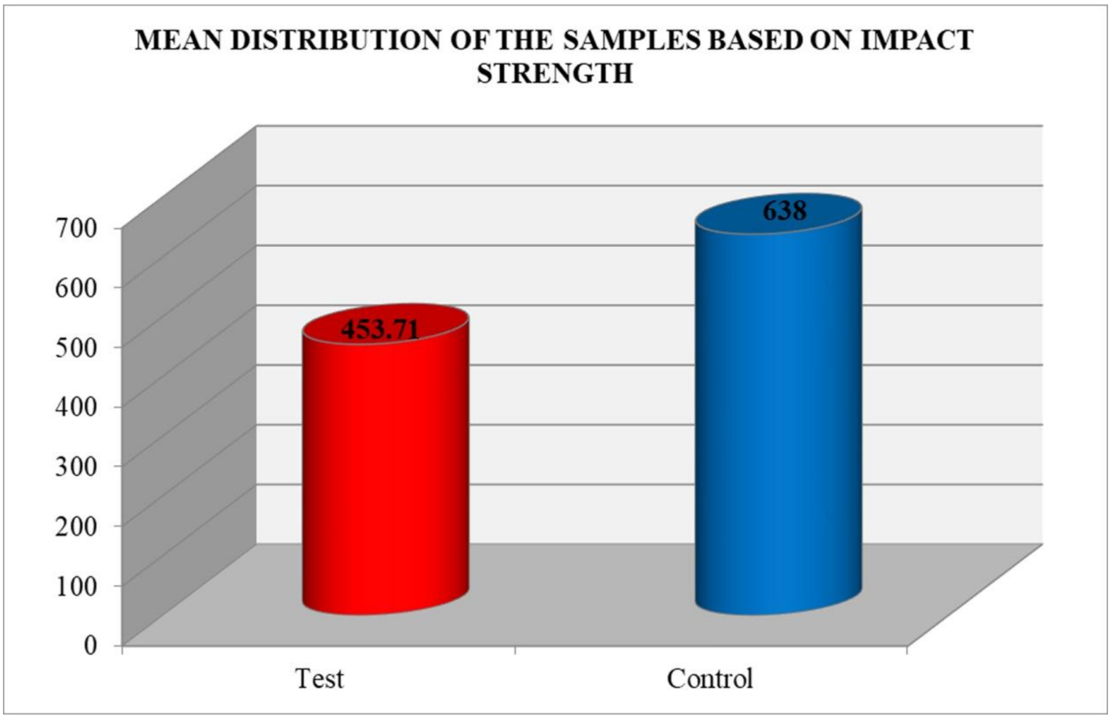

Figure 5

TABLE 1: MEAN DISTRIBUTION OF THE SAMPLES BASED ON TENSILE STRENGTH AND MAXIMUM LOAD APPLIED

Groups		Sample size	Minimum	Maximum	Mean	Standard Deviation
Test Group B	Maximum Load	35	1108.30	2290.66	1774.78	326.11
	Tensile Strength	35	31.59	57.76	44.16	7.48
Control Group A	Maximum Load	35	1149.50	2284.50	1663.24	300.10
	Tensile Strength	35	30.23	55.49	41.85	8.15

TABLE 2: MEAN DISTRIBUTION OF THE SAMPLES BASED ON IMPACT VALUE AND IMPACT STRENGTH APPLIED

Groups		Sample size	Minimum	Maximum	Mean	Standard. Deviation
Test Group D	Impact value	35	0.44	1.38	0.8777	0.24411
	Impact strength	35	310.00	645.00	453.71	106.95
Control Group C	Impact value	35	0.54	2.70	1.1277	0.44931
	Impact strength	35	300.00	1550.00	638.00	352.83

TABLE 3: COMPARISION OF TENSILE AND IMPACT STRENGTH BETWEEN TEST AND CONTROL GROUPS USING INDEPENDENT SAMPLE T TEST

	Mean difference	t value	P value
Tensile strength	2.31	1.23	0.22
Impact strength	-184.28	-2.9	0.004*

*-Significant, t- value- Independent sample t- test, p- value - Probability