# EFFECT OF SPOT WELDING AND LASER WELDING ON THE BOND STRENGTH OF CERAMIC TO LASER SINTERED CO-CR METAL CERAMIC ALLOY - AN *IN VITRO* STUDY

By

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Under the guidance of

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I hereby declare that this dissertation entitled "*Effect of spot welding and laser welding on the bond strength of ceramic to laser sintered Co-Cr metal ceramic alloy*" is a bonafide and genuine research work carried out by me under the guidance of **Prof. Dr. George Francis**, Head of the Department, Department of Prosthodontics Crown & Bridge, St Gregorios Dental College, Chelad, Kothamangalam.

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# ABSTRACT

**Background & Objectives: -** Long span FPDs sometimes have to be sectioned and re-positioned if fit is inadequate. The method of joining them would be by soldering or welding. This study was conducted to evaluate the effect of laser welding and spot welding on the micro-tensile bond strength between ceramic and direct Metal Laser Sintered Co-Cr metal alloy

**Methods: -** Two blocks of size 5x5x5mm were designed using CAD-CAM software (AutoCAD® AutoDesk 2015). One of the blocks was designed with a groove of 1.5mm depth and 1mm width which ran along the entire length of the surface it was designed on. The designs were transferred to the CAD-CAM software, CAMWorks® Solids SolidWorks© and Direct Metal Laser Sintering was done on Co-Cr metal alloy powder to produce 30 blocks. Ten blocks without the groove were furnished and these were marked as Control group, Group C. Twenty blocks with the groove was fabricated and divided into 2 groups of 10 each. They were divided into two groups. The first group was labelled as Group L for laser sintering and the second one as Group S for spot welding. The groove within blocks of Group L and S were filled with a DENTARUM Co-Cr Schweibraht welding wire and welded respectively. Following this, 2 layers of opaque porcelain (Opaque Porcelain - Ivoclar IPS Classic Programat P300) were added on one of the surfaces of blocks in Group C and the welded surface of all blocks in Groups L & S followed by build up with dentin ceramic (Ivoclar IPS Classic Dentin) and enamel ceramic (Ivoclar IPS Classic Enamel) to achieve a total ceramic thickness of 2mm.

To test the micro-tensile bond strength, 2 custom aluminium jigs were fabricated since the stock jigs on a universal testing machine could not hold the small sized blocks. The aluminium jigs had two screw heads where the blocks could be fastened. The aluminium jigs were then tightened onto the stock jigs of the universal testing machine (Fine testing machine- TFUN400) used in tension at a crosshead speed of 1mm/min and bond strength was evaluated.

**Results & Discussion:-** Once the specimens were tested for micro-tensile bond strength, it was observed that there was a significant difference in the micro-tensile bond strength between the non-welded blocks and the welded blocks ($P<0.05$) which suggested that welding could reduce the micro-tensile bond strength between porcelain and Co-Cr metal alloy.

**Conclusion:-** Spot welding and laser welding significantly decreased the micro-tensile bond strength of a veneering ceramic to a base metal.

**Keywords:-** Mirco-tensile bond strength, Laser welding, Spot welding, Direct Metal Laser Sintering.

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# INTRODUCTION

Metal ceramic (MC) restorations are commonly provided in dental practice, primarily because of their acceptable biological, mechanical, and aesthetic properties. The success of these restorations depends on various factors. The main factor being, presence of a strong bond between porcelain and the metal substructure [(1)]. Noble metal alloys are generally preferred for the metal frameworks, because of their biocompatibility, good mechanical properties, and excellent ceramic-to-metal bond; however, base metal casting alloys are extensively used worldwide because of economic considerations [(2)].

Dental alloys are frequently used for either replacing a completely/partially distorted structure or to restore the disturbed function of the orofacial organ. Some of the common applications in dentistry are of decayed tooth reconstruction in particular enamel, dentin with the help of crowns, and fillings, missing teeth replacement by the use of removable dentures, or surgical prostheses. This kind of restoration or replacement involves morphological, physiological, as well as psychological re-formation of the patient apart from their main purpose of preventing structural decay and functional failure. The selection of dental alloys needs to consider biological aspects and its technical feasibility. Biological aspects consider chemical and functional biocompatibility other than technical functionality.

Long span FDPs have always been a challenging effort in clinical dentistry mainly due to the difficulty in establishing good amount of stability and clinical condition of the abutments [(3)].

Conventional casting techniques have proven notable differences in clinical scenarios especially in long term survivability [(4)]. Direct Metal Laser sintering has proven to be a good and effective choice for fabrication of long span FDPs with better clinical survivability [(5)] and better marginal adaptation when compared to conventional casting techniques due to lesser metal ion leaching [(6)]. Direct Metal Laser Sintering has also proven as a viable option in the medical field due to its accuracy to produce the input CAD/CAM image much that it has been used to produce titanium mesh which aided in bone regeneration.

Andres et al found that the marginal fit and internal fit of DMLS produced FPDs were the best as opposed to the lost wax technique [(7)]. However, conventional casting techniques showed no significant changes in fit when DMLS was done with single crowns, where both the procedures showed comparable fit with low internal gap [8]. DMLS generally uses Co-Cr metal alloy powder but Ni-Cr may be used as well. Nickel allergy is several patients could pave the way for Cobalt-Chromium dental alloys which have proven to have more strength [9] and more corrosion resistance[10]. Moreover Cobalt Chromium has more color stability and biocompatibility as opposed to Ni-Cr thus favoring the use of Co-Cr. The same has been used even as an implant material of choice for orthopedic implants.

Min-Ho Hong et al described better biocompatibility of Ni-Cr alloys which were cast using DMLS as opposed to those that were conventionally cast since there was less Ni ion leaching as opposed to the conventionally cast alloy. For longer span FPDs, Co-Cr is the material of choice due to its better biocompatibility [11]. In some instances, long span FPDs may have to be sectioned and welded to attain better fit of the prosthesis. Generally, welding and soldering processes are essential for the development of virtually every manufactured product. However, these processes often appear to consume greater fractions of the product cost and to create more of the production difficulties than might be expected. There are a number of reasons that explain this situation.

First, welding and joining are multifaceted, both in terms of process variations (such as fastening, adhesive bonding, soldering, brazing, arc welding, diffusion bonding, and resistance welding) and in the ordinances needed for problem solving (such as mechanics, materials science, physics, chemistry, and electronics).

Second, welding or joining difficulties usually occur far into the manufacturing process, and the relative value of scrap parts is higher than accounted for at the beginning of the procedure.

Third, a very large percentage of product failures occur at joints because they are usually located at high stress points in an assembly and are therefore the weakest parts of that assembly. Careful attention to the joining processes can produce great rewards in manufacturing economy and in product reliability.

Welding and soldering although primarily are used in the field of engineering, dentistry has much use of the same as; it is a relatively common practice in dentistry to obtain one-piece cast frameworks. Welding or soldering if not performed carefully by a professional can be a process that incorporates numerous errors and can lead to an unsatisfying result. [12]

One-piece cast metal frameworks over teeth should be avoided, because their apparent fit is at the expense of tooth movement, developing areas of pressure and traction within the periodontal ligament. The same is true for frameworks over implants as well since osseo integrated implants are rigidly connected to the surrounding bone, and this connection lacks the inherent resilience of the periodontal ligament. It has been documented that implant movement within the bone is limited to 50–150 μm [13]. In case of a misfit between implant and abutment, or prosthesis, it is bone deformation that causes implant movement. Thus, compressive and tensile loads could be directed to the restoration, which could result in a loosening of the prosthesis and abutment screws, fracture of the restoration, bone micro-fractures surrounding the implants, and even fracture of the implant.

The fabrication of a metal framework of multiple elements cast in one piece is not suitable for dental work, because it is potentially threatening to framework fit. Casting separated fragments for subsequent welding is preferred. Barbosa et al [14] comparatively analyzed, by SEM, the vertical and horizontal fit between UCLA abutments and implants used in frameworks of five elements that were cast in one piece after laser welding. Three different materials were used: titanium CP (grade 1), Co-Cr alloys, and Ni-Cr-Ti alloys. The passive fit of the frameworks was evaluated by testing the single screw and the stresses generated around the implants, by photoelasticity tests. There was a statistically significant improvement in the fit of all framework materials after sectioning and laser welding.

The welding procedures are advised, regardless of the extension of the metal structure, on prosthesis over teeth or implants. In dentistry, different welding techniques are used among which brazing, Tungsten Inert Gas, Plasma Arc Welding, and laser welding are the best choice for getting excellent results.

Similarly, long span FDPs may tend to lift due to inadequate fit on one of the abutments. In such cases as well, FPDs may be sectioned, reseated and welded or soldered to achieve adequate fit of the prosthesis. This has been found to be a viable alternative.

Studies have also shown that Laser welding is a better alternative to soldering wherein better strength can be created during welding as opposed to soldering [16], [17], [18]. However, these techniques would prove useless if a factor that is, aesthetics is not considered. Ceramics are the source of esthetics in a crown. Clinically acceptable bond between ceramic and the substructure metal is profound in creating an apt metal ceramic restoration. Metal and ceramic form a bond which includes the positive features of metal (strength, durability and stability) and ceramics (esthetics). A strong bond between the metal and ceramic is the basic prerequisite for the durability of the metal-ceramic restoration [18]. The heating of metal construction results in the diffusion of certain atoms on the surface. Here they react with atmospheric oxygen creating oxides which remain on the cast surface, since the reversible diffusion is prevented. Atoms of silica in ceramic are bound with these oxides as a result of which a metal-tracer-ceramic compound is formed and a chemical bond is formed. In addition to forming an oxide layer, the oxidation heat treatment (OHT) is applied for all alloys to remove the entrapped gas and eliminate surface contaminants. Surface treatment before porcelain application may also affect the bond strength of metal and ceramics. Roughened surfaces created by sandblasting enables mechanical interlocking and an increased surface for bonding metal and ceramics. Applying a bonding agent may improve the quality of the bond of certain metal-ceramic restorations.

This study is intended to evaluate the micro-tensile bond strength between ceramic and Co-Cr metal alloy after welding when they are subjected to a shear force and thus comprehend if welding decreases or increases the bond strength between ceramic and metal alloy.

The null hypothesis was considered as that welding would not have an effect on the micro-tensile bond strength between Direct Metal Laser Sintered Co-Cr metal alloy and veneering ceramic.

# AIMS AND OBJECTIVES

**AIM:-**

The aim of the current study was to investigate the effect of Spot Welding and Laser Welding on the micro-tensile bond strength between ceramic and Laser Sintered Co-Cr Metal Ceramic Alloy.

**OBJECTIVES:-**

The objectives of the current study were:-

1. To measure the micro-tensile bond strength between metal and ceramic without Welding.
2. To measure the micro-tensile bond strength between metal and ceramic after Spot Welding.
3. To measure the micro-tensile bond strength between metal and ceramic after Laser Welding.
4. To compare the micro-tensile bond strength without welding and after welding.

# REVIEW OF LITERATURE AND BACKGROUND

- **Galindo et al**, [18] in 2001 studied the effect of solder on the bond strength between metal and porcelain. The mean fracture load for test samples was significantly greater than for control samples. Test samples also were significantly thicker (mean thickness difference 0.14 mm). When the data were controlled for thickness by using a multiple linear regression analysis, no significant difference was found. In this study, soldered and non-soldered samples did not show any significant difference in porcelain-to-metal bond strength.

- **Bertrand et al**, [15] conducted a study in 2001 to assess the accuracy, quality and reproducibility of laser welding as applied to Ni-Cr-Mo and Co-Cr-Mo alloys which are often used to make prosthesis. The alloy's ability to weld was evaluated with a pulsed Nd-Yag Laser equipment. In order to evaluate the joining, various cast wires with different diameters were used. The efficiency of the joining was measured with tensile tests. Metallographic examinations and x-ray microprobe analysis were performed through the welded area and compared with the cast part. It was found that a very slight change in the chemistry of the Ni-Cr alloys had a strong influence on the quality of the joining. The Co-Cr alloy presented an excellent weldability. A very important change in the microstructure due to the effect of the laser was pointed out in the welding zone, increasing its micro-hardness. The higher level of carbon and boron in one of the two Ni-Cr samples was found to be responsible for its poor welding ability.

- In 2002, **E. Denkhaus et al**, [19] did a review on Nickel allergy, since there is an increasing utilization of heavy metals in modern industries leads to an increase in the environmental burden. Nickel has been known to be a good example of a metal whose use is widening in modern technologies. As the result of accelerated consumption of nickel-containing products nickel, compounds are released to the environment in all stages of production and utilization. Their accumulation in the environment represents serious hazard to human health. Some of the known health related effects of nickel are skin allergies, lung fibrosis, variable degrees of kidney and cardiovascular system poisoning and stimulation of neoplastic transformation. The mechanism of the effect is not exactly known and is a subject of detailed investigation.

- **Min Sok Kang et al**, [20] in 2003 conducted a study that assessed the influence of solder on the porcelain failure load between metal and porcelain, using crown-shaped specimens. Forty standardized crown patterns were fabricated on a metal die and cast with a noble alloy. The specimens were divided into test (soldered - n=20) and control (non-soldered, n=20) groups. Soldered metal-porcelain crown specimens demonstrated a significantly lower load at failure. Within the limits of this study, it was concluded that soldering may negatively affect porcelain-metal crowns.

- **Hercules Jorge et al**, [21] in 2003 conducted a study to evaluate the shear bond strength of four materials used as aesthetic material, and bonded to Ni–Cr alloy. Sixty-eight alloy discs were prepared and equally divided into four groups. They received four treatments for veneering: conventional feldspathic porcelain (Noritake EX-3) and three light-cured prosthodontic composite resins Artglass, Solidex and Targis respecively. The aesthetic materials were applied after metal structure conditioning according to the manufacturers' recommendations. For composites, the highest mean shear bond strength was observed for Targis; followed by Solidex  and Artglass. Optical analysis of the fractured surfaces indicated that Targis and Noritake EX-3 had all failures as a mixture of both cohesive and adhesive patterns. Whereas, for Artglass and Solidex, the fractures were mainly adhesive in nature. The Solidex system was almost equal to the Targis system in bond strength and exhibited greater strength than the Artglass system. The study concluded that porcelain fused-to-metal showed considerably higher shear bond strength than the three metal–resin bonding techniques.

- **N. Baba et al**, [22] in 2004 conducted a study to investigate the effect of the output energy of laser welding and welding methods on the joint strength of cobalt– chromium (Co-Cr) alloy. Two types of Co-Cr plates were prepared and transverse sections were made at thecenter of the plate. The cut surfaces were joined and welded with a laser-welding machine at several levels of output energy with the use of two methods. The force required to break specimens was determined by means of tensile testing. The force required to break the 0.5-mm laser-welded specimens at currents of 270 and 300 A was not statistically different from the results for the non-welded control specimens. The force required to break the 1mm specimens that were double-welded at a current of 270 A had the highest value among the 1mm laser-welded specimens. The results suggested that laser welding under the appropriate conditions improved the joint strength of cobalt– chromium alloy.

- In 2004, **M.A. Ameer et al** [23] studied the Corrosion behaviour of dental alloys in artificial saliva using different chemical and electrochemical techniques. The order of corrosion rate for the three alloys in artificial saliva is: wironit < wirolloy < wiron99. This order agrees with the results of chemical studies for determining the cumulative ion concentration using ICP/MS. The concentration of wiron99 Ni-Cr alloy is greater since it had 9.5% Mo whereas wirolloy had 3% and wironit had 5%. The higher corrosion rate of wiron99 compared to wirolloy is due to presence of high concentration of Mo. Increasing casting number leads to decrease charge transfer resistance value and increasing capacitance. Wironit had greater amount of Cr which helped reduce its corrosion although its Mo levels were higher compared to wirolloy.

- **Srimaneepong V et al**, [24] in 2005 conducted a study to compare the mechanical properties of laser-welded castings of Ti-6Al-7Nb alloy, CP Ti, and Co-Cr alloy and compare them to the unwelded castings using a tensile test. This study proved that the mechanical strength of laser-welded Ti-6Al-7Nb alloy and CP Ti castings was as high as that of unwelded castings, while the mechanical properties of laser-welded alloy joints were influenced by microstructural changes.

- **A. Bindl et al**, [25] in 2005 conducted a study for the evaluation of the marginal and internal fit of all-ceramic molar crown-copings hypothesizing that Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) fabrication shows the same accuracy of fit as conventional techniques. A set of six individual crown preparations were duplicated 12 times yielding 72 plaster dies. Slip-cast (In-Ceram Zirconia), heat-pressing (Empress Il) and CAD/CAM crown-copings (Cerec inLab, DCS, Decim and Procera) were seated on 12 dies each. Marginal and internal gap width were measured in the SEM at 120x magnification. Marginal gap of slipcast was significantly smaller than that of Empress II copings. Procera and Decim did not differ from slip-cast but instead were smaller than Empress II and Cerec inLab DCS did not differ from any of the others. The internal gap width of Procera was larger than that of Decim and slip-cast while Empress II, DCS and Cerec inLab did not differ significantly from Decim, Procera and the slip-cast. Internal mesiodistal gap width was similar among each other. The fit of conventional and CAD/CAM all-ceramic molar crown-copings covered the same range of gap width confirming the assumed hypothesis that fabrication of crown coping using conventional technique and CAD-CAM showed similar accuracy in fit.

- **Y. Kokubo et al**, [(26)] in 2005 conducted a study that evaluated the marginal and internal gaps of Procera AllCeram crowns in vivo using silicone materials. Ninety Procera AllCeram crowns were evaluated before final cementation. White and black silicone materials were used to record the marginal fit and internal fit. The crowns were then sectioned bucco-lingually and mesio-distally to measure the thickness of the silicone layer using a microscope. The mean values of the marginal gaps were the smallest in all tooth groups, whereas those at the rounded slope of the chamfer were the largest. There were significant differences in the mean gaps at the four reference points (margin, rounded slope of the chamfer, axial wall and occlusal surface) in each group, except for the molar teeth. The study concluded on the note that, the mean marginal gaps of the Procera AllCeram crowns was found to be within the range of clinical acceptance.

- **Nikellis et al**, in 2005 [(27)] conducted a study to investigate the effect of soldering on metal-ceramic bond strength of a representative Ni-Cr base metal alloy. Twenty-eight rectangular Ni-based alloy (Wiron 99) specimens were equally divided into soldering and reference groups. Soldering group specimens were covered with a 0.1-mm layer of the appropriate solder and reduced by 0.1 mm on the opposite side. Five specimens of each group were used for the measurement of surface roughness parameter and hardness, and 3 were used for measurement of the modulus of elasticity. Statistical analysis of the surface roughness parameter and bond strength failed to reveal any significant difference between the 2 groups. Under the conditions of the present study, the addition of solder to the base metal alloy did not affect the metal-ceramic bond strength. Evaluating the effect of soldering on the metal-ceramic bond strength of a Ni-Cr base alloy, of 28 specimens found that soldering did not affect the metal-ceramic bond strength

- **Koray Soygun et al**, in 2005 [28] evaluated the color stability of three bio-ceramic materials, [IPS Empress CAD, IPS e.max CAD , and Lava Ultimate CAD] were treated with three commercial mouthrinses [Listerine, Tantum Verde, and Klorhex]; and changes in colour reflectance and surface roughness values were then quantitatively assessed. The study determined that there was a positive correlation between the color reflectance and increase in the surface roughness. Two of the ceramic materials, IPS Empress and Lava Ultimate, were affected significantly by the treatment of the mouth rinse solutions. The most affecting solution was Tantum Verde and the most affected material was Lava Ultimate. As expected, the most resistant material to color change and chemical corrosion was IPS emax CAD among the materials used. This work implied that mouth rinse with lower alcohol content had less deteriorating effect on colour and on the surface morphology of the bioceramic materials.

- **Renata Marques de Melo et al**, [29] in 2005 conducted a study to evaluate the shear bond strengths of IPS emax porcelain system to Ni-Cr alloys and Co-Cr alloys. They found no significant difference in the bond strength between the different alloy systems.

- **Hussaini et al**, [30] conducted a study in 2005 to evaluate the effect of surface treatment on bond strength of porcelain to cP-Ti and found that surface treatment with airborne particles with $SiO_2$ or bonding agent enhanced the bond strength of Ti-porcelain.

- **Yonglie Chao et al** [31], in 2005 conducted a study to compare the surface characteristics, microstructure, and magnetic retentive forces for a dowel and coping–keeper mechanism fabricated using a laser welding process and a cast-to casting technique. Five cast-to and six laser-welded dowel and coping–keeper specimens were tested. Statistically significant differences in vertical magnetic retentive force were found between the control group and both the laser-welded and cast groups. Compared with the cast dowel-keepers, the average vertical magnetic retentive force of the laser-welded dowel-keepers was significantly higher. As, concluded by the study, the laser welding technique had less influence on the surface characteristics, the microstructure, and the magnetic retentive forces of keepers relative to techniques that incorporate a keeper at the time of cast dowel and coping fabrication.

- **Regina et al**, in 2006 (32) conducted a study evaluating the micro-tensile bond strength of cement to ceramic by using thirty blocks of In-Ceram Zirconia, Ten of which were abraded using 110micron Aluminium Oxide particles, ten using 110micron Silicon di-oxide. ten were also air blasted using 30micron Silicon di-oxide particles. It was found that the silica blasted blocks had better bond than the ones blasted with Aluminium Di-Oxide.

- **Rok Zupancic et al** (33) in 2006, conducted a study to determine which joining method offers the best properties to cobalt-chromium alloy frameworks. Brazed and two types of laser-welded joints were compared for their mechanical and corrosion characteristics. The fracture surfaces and corrosion defects were examined with a scanning electron microscope. Electrochemical measurements indicated that the corrosion resistance of the laser-welded joints was better than of the brazed ones, primarily due to differences in passivation ability. Laser welding provides excellent corrosion resistance to cobalt-chromium alloy joints, but strength is limited due to the shallow weld penetration. Thus the study concluded that brazed joints are less resistant to corrosion but have higher tensile strength than laser welded joints.

- **Watanabe et al** (34) in 2006, conducted a study to investigate the effect of argon gas shielding on the strengths of laser-welded cast Ti and Ti-6Al-7Nb and compared the results to those of two dental casting alloys. The failure loads of argon-shielded laser-welded CP Ti and Ti-6Al-7Nb were greater compared to the failure loads of specimens welded without argon shielding for both three and five-spot welding. Regardless of argon shielding, the failure loads of the laser-welded gold alloy was approximately half that of the control specimens. In contrast, the failure loads of the non-shielded laser-welded Co-Cr alloy were greater. The percent elongations positively correlated with the failure loads. The study concluded stating that the use of argon shielding is necessary for effective laser-welding of CP Titanium and Ti-6Al-7Nb but not for gold and Co-Cr alloy.

- **Rick Rocha**, [35] in 2006 conducted a study to assess, using the flexural strength testing, the efficacy of two processes Nd:YAG laser and TIG (tungsten inert gas) for welding of pure Titanium, Co-Cr and Ni-Cr alloys. The study determined that there were significant differences among the non-welded materials, the Co-Cr alloy being the most resistant to deflection. Comparing the welding processes, significant differences where found between Tungster inert Gas welding and laser welding as well as, between laser alone and laser plus filling material. In conclusion, TIG welding yielded higher flexural strength means than Nd:YAG laser welding for the tested Ti, Co-Cr and Ni-Cr alloys.

- In 2007 **Susana M. et al**, [36] did a study to evaluate the shear bond strength of Co-Cr and Ni-Cr metal alloys and a specific ceramic, submitted to different thermocycling immersion times. Sixty metal-ceramic specimens were confectioned and standardized in cylindrical format. Three thermocycling conditions were evaluated: without thermocycling, 3.000 cycles with 30s of immersion time and 3.000 cycles with 60s. The results didn't show significant statistic differences between the metal-porcelain combinations. Nevertheless, both metal-ceramic systems submitted to 60s of immersion time showed lower values compared to specimens without thermocycling. It was concluded that the thermocycling immersion time of 1 minute affect the shear bond strength values for the Ni- Cr/porcelain and Cr-Co/porcelain systems.

- **T. Traini et al**, [37] in 2008 conducted a study that focused on a titanium alloy implants incorporating a gradient of porosity, from the inner core to the outer surface, obtained by laser sintering of metal powder. Surface appearance, microstructure, composition, mechanical properties and fractography were evaluated. The surface roughness was investigated using a confocal scanning laser microscope. The study determined that laser metal sintering proved to be an efficient means of construction of dental implants with a functionally graded material which is better adapted to the elastic properties of the bone. Such implants should minimize stress shielding effects and improve long-term performance.

- **Tolga Akova et al**, [38] in 2008 conducted a study to compare shear bond strengths of cast Ni–Cr and Co–Cr alloys and the laser-sintered Co–Cr alloy to dental porcelain. Dental porcelain was applied on two cast and one laser-sintered base metal alloy. Ten specimens were prepared for each group for bond strength comparison. While the mean shear bond strength was highest for the cast Ni–Cr metal–ceramic specimens, the bond strength was not significantly different from that for the cast Co–Cr metal–ceramic specimens and the laser-sintered Co–Cr metal–ceramic specimens. All metal–ceramic specimens prepared from cast Ni–Cr and Co–Cr alloys exhibit a mixed mode of cohesive and adhesive failure, whereas five of the metal–ceramic specimens prepared from the laser-sintered Co–Cr alloy exhibited the mixed failure mode and five specimens exhibited adhesive failure in the porcelain. The new laser-sintering technique for Co–Cr alloy appears promising for dental applications, but additional studies of properties of the laser-sintered alloy and fit of castings prepared by this new technique are needed before its acceptance into dental laboratory practice. Laser sintering of Co–Cr alloy seems to be an alternative technique to conventional casting of dental alloys for porcelain fused to metal restorations.

- **Jens Johannes et al** [39] in 2008, did a study the aim of which was to compare the mechanical strength of different joints made by conventional brazing, Tungsten Inert Gas and laser welding with and without filling material. Five standardized joining configurations of orthodontic wire in spring hard quality were used: round, cross, 3 mm length, 9 mm length and 7 mm to orthodontic band. The joints were made by five different methods: brazing, tungsten inert gas (TIG) and laser welding with and without filling material. The highest fracture strength means were observed for laser welding with filling material and 3 mm joint length. Using filling materials, there was a clear tendency to higher mean values of fracture strength in TIG and laser welding. However, statistically significant differences were found only in the 9-mm long joints. In conclusion, the fracture strength of welded joints was positively influenced by the additional use of filling material. TIG welding was comparable to laser welding except for the impossibility of joining orthodontic wire with orthodontic band comparing the fracture strength of Gas Spot welding and laser welding by connecting two orthodontic wires and found that the fracture strengths of both were comparable

- **Katrin Quante et al**, [40] in 2008 conducted a study, the purpose of this in vivo investigation was to evaluate the marginal and internal fit of metal-ceramic crowns fabricated with a new laser melting procedure, and to investigate the influence of ceramic firing on the marginal and internal accuracy of these crowns. After tooth preparation, impression taking using polyvinylsiloxane and model casting, each preparation was contact less scanned by strip-light-projection. The finishing line and the virtual construction of the metal coping were defined by means of a computer. Using CAD/CAM software the metal copings were produced by BEGO Medical. A base metal alloy (Wirobond C) and a precious alloy were used in this study with 14 restorations each. The internal and marginal accuracy of the specimens were examined using a silicone indicator paste. The results of this *in vivo* study show that crowns produced with laser melting technology exhibit a marginal and internal accuracy that is comparable to conventional production procedures.

- **Yurdanur Ucar et al** [8] in 2009, conducted a study to compare the internal fit of laser-sintered Co-Cr alloy crowns with base metal restorations prepared from another Co-Cr alloy and a Ni-Cr alloy using conventional casting techniques. Internal fit of laser-sintered Co-Cr crowns was compared with the fit of conventionally cast Ni-Cr and Co-Cr alloy crowns. Twelve crown-shaped specimens were prepared on a stainless steel die representing a prepared maxillary right central incisor for each group. Fit of crowns was evaluated using 2 different techniques: (1) weighing the light-body addition silicone that simulated a cement material, and (2) measuring the internal gap width on a die for longitudinally sectioned specimens. One-way ANOVA followed by Tukey multiple comparison test was used for statistical analysis. No significant difference was observed between the 3 groups for internal gap. The study concluded that weighing the light-body addition silicone is a convenient method for evaluating the 3-dimensional internal fit of dental crowns. However, no significant difference was found among the 3 alloy groups evaluated for the internal gap width of sectioned crown specimens.

- **Aguiar et al**, [41] in 2009 did a study to compare the accuracy of fit of implant supported framework cast in Ni-Cr alloy with and without laser welding and concluded that there was no significant difference in the fit between the samples but improved the fit once the frameworks were laser welded.

- **Rodrigo et al** [42] in 2009 conducted a study to evaluate the influence of laser welding applied to commercially pure titanium (CpTi) substructure on the bond strength of commercial ceramic. The influence of airborne particle abrasion (Aluminum Oxide – $Al_2O_3$) conditions was also studied. Forty CpTi cylindrical rods were cast and divided into 2 groups: with laser welding and without laser welding. Significant differences were found among all subgroups. The highest and the lowest bond strength means were recorded in the group without laser welding and sandblasted using Aluminum Oxide - 110µm and Laser welded using Aluminum Oxide - 50µm, respectively. Airborne particle abrasion yielded significantly lower bond strength as the $Al_2O_3$ particle size decreased. Mechanical retention decreased in the laser-welded specimens, i.e. the metal-ceramic tensile bond strength was lower.

- **Barbosa et al** [14] in 2010 comparatively analyzed, by SEM, the vertical and horizontal fit between UCLA abutments and implants used in frameworks of five elements that were cast in one piece after laser welding. Three different materials were used: titanium CP (grade 1), Co-Cr alloys, and Ni-Cr-Ti alloys. The passive fit of the frameworks was evaluated by testing the single screw and the stresses generated around the implants, by means of photoelasticity. There was a statistically significant improvement in the frameworks fit for all materials after sectioning and laser welding.

- **Christian Ritzberg et al**, [43] in 2010 conducted a study; the main properties (mechanical, thermal and chemical) and clinical application for dental restoration were demonstrated for three types of glass-ceramics and sintered polycrystalline ceramic produced by Ivoclar Vivadent AG. Two types of glass-ceramics are derived from the leucite-type and the lithium disilicate-type. The third type of dental materials represents a $ZrO_2$ ceramic. CAD/CAM technology is a procedure to manufacture dental ceramic restoration. Leucite-type glass-ceramics demonstrate high translucency, preferable optical/mechanical properties and an application as dental inlays, onlays and crowns. Based on an improvement of the mechanical parameters, specially the strength and toughness, the lithium disilicate glass-ceramics are used as crowns; applying a procedure to machine an intermediate product and producing the final glass-ceramic by an additional heat treatment. Small dental bridges of lithium disilicate glass-ceramic were fabricated using a molding technology. $ZrO_2$ ceramics show high toughness and strength and were veneered with fluoroapatite glass-ceramic. Machining is possible with a porous intermediate product.

- **Jing Qiu et al**, (44) conducted a study in 2010 evaluating the corrosion behavior and surface properties of a commercial cobalt–chromium alloy and two nickel–chromium alloys [beryllium-free and Be-containing] before and after a simulated porcelain-firing process. Before porcelain firing, the microstructure, surface composition and hardness, electrochemical corrosion properties, and metal-ion release of as-cast alloy specimens were examined. After firing, similar alloy specimens were examined for the same properties. In both as-cast and fired conditions, the Co–Cr alloy (Wirobond C) showed significantly more resistance to corrosion than the two Ni–Cr alloys.
- **Andres Ortorpa**, (7) in 2010 conducted a study to evaluate and compare the marginal and internal fit in vitro of three-unit FDPs in Co–Cr made using four fabrication techniques, and to conclude in which area the largest misfit is present. Best fit was found in the DLMS group followed by Milled wax with lost-wax, Lost Wax and Milled Co-Cr. In all four groups, best fit in both abutments was along the axial walls and in the deepest part of the chamfer preparation. The greatest misfit was present occlusally in all specimens.
- **Aladag et al**, (3) in 2011 conducted a study to evaluate the effect of soldering and laser-welding procedures on the bond strength between ceramic and metal. Vickers hardness measurements were made after polishing the surfaces with a metallographic polishing kit. A veneering ceramic was vibrated, condensed in a mold, and fired on the metal frameworks. The specimens were sectioned in 2

axes to obtain non-trimmed bar specimens with a bonding area of approximately 1 $mm^2$. Forty bars per block were obtained. Each bar was subjected to microtensile bond strength (μTBS) testing with a crosshead speed of 1 mm/min. The μTBS data (MPa) were recorded, and SEM was used for failure analysis of the tested bars. The mean differences in μTBS of veneering ceramic to soldered and laser-welded metal surfaces were not significantly different and were significantly lower than that of the cast alloy. The mean Vickers hardness of cast alloy was significantly higher than soldered and laser-welded groups. Soldering and laser welding significantly decreased the μTBS of a veneering ceramic to a base metal alloy. The study evaluated the effect of soldering and laser welding on the bond strength of ceramic to metal and found out that soldering and laser welding significantly decreased the bond strength of ceramic. The bond strength of laser welded metal ceramic was higher than the soldered counterpart.

- **AbouTara et al**, [(45)] in 2011 conducted a study that evaluated the clinical outcome of posterior single-unit metal-ceramic crowns fabricated using computer-aided design/computer-assisted manufacture laser-sintering technology. Sixty restorations were placed in 39 patients and cemented with glass-ionomer cement. Follow-ups were performed annually. During a mean observation period of 47 months, one restoration was regarded a dropout, one crown failed (biologic failure), and one debonded. One abutment tooth had to be treated endodontically, and three teeth were treated because of caries. No further technical complications like, veneering ceramic chipping, occurred during the observation period. The results suggest that the clinical outcome of posterior single-unit metal-ceramic crowns fabricated using laser-sintering technology is promising.

- **Srinivasa et al** [(12)] in 2011conducted a study, by using samples of three commercially available nickel-chrome (Ni-Cr) casting alloys (Dentaurum, Bego, Sankin) to assess their corrosion behavior, using potentiodynamic polarization method with fusayama artificial saliva as an electrolyte medium to check for their biocompatibility. The parameters for corrosion rate and corrosion resistance were obtained from computer-controlled corrosion schematic instrument, namely, potentiostat through corrosion software. It was concluded that Dentarum and Bego showed satisfactory corrosive behavior, with exception of Sankin which depicted higher corrosion rate and least resistance to corrosion. Thus, the selection of an alloy should be made on the basis of corrosion resistance and biologic data from dental manufactures.found that Dentarum had the most satisfactory corrosion resistance.

- **Ciocca et al**, [46] in 2011 conducted a study that describes a protocol for the direct manufacturing of a customized titanium mesh using CAD–CAM procedures and rapid prototyping to augment maxillary bone and minimize surgery when severe atrophy or post-oncological deformities are present. Titanium mesh and particulate autogenous plus bovine demineralised bone were planned for patient rehabilitation. Bone augmentation planning was performed using the pre-op CT data set in relation to the prosthetic demands, minimizing the bone volume to augment at the minimum necessary for implants. The containment mesh design was used to prototype the 0.6 mm thickness customized titanium mesh, by direct metal laser sintering. The levels of regenerated bone were calculated using the post-op CT data set, through comparison with the pre-op CT data set. All planned implants were positioned after an 8 month healing period using two-step implant surgery, and finally restored with a partial fixed prosthesis. Thus, 3D printing of Titanium mesh is a viable and reproducible method to determine the correct bone augmentation prior to implant placement and CAD–CAM to produce a customized direct laser-sintered titanium mesh that can be used for bone regeneration.

- **Madhan Kumar et al**, [47] in 2012 conducted a study to evaluate the efficacy of laser welding and conventional welding on the tensile strength and ultimate tensile strength of the cobalt– chromium alloy. Samples were prepared with two commercially available cobalt–chromium alloys (Wironium plus and Diadur alloy). The samples were sectioned and the broken fragments were joined using Conventional and Laser welding techniques. The welded joints were subjected to tensile and ultimate tensile strength testing; and scanning electron microscope to evaluate the surface characteristics at the welded site. Both on laser welding as well as on conventional welding technique, Diadur alloy samples showed lesser values when tested for tensile and ultimate tensile strength when compared to Wironium plus alloys.

- In 2012, **Nan Xiang et al** [48] conducted a study to evaluate the metal-ceramic bond strength of a Co-Cr dental alloy prepared using a selective laser melting (SLM) technique. Two groups comprised of twenty Co-Cr metal bars each were prepared using either a SLM or traditional lost-wax casting method. SEM/EDS analysis indicated a mixed fracture mode on the debonding interface of both the SLM and the cast groups, the SLM group showed significantly more porcelain adherence than the control group ($p<0.05$). The SLM metal-ceramic system exhibited a bonding strength that exceeds the requirement of ISO 9691:1999(E) and it even showed a better porcelain adherence test comparable to traditional cast methods.

- **Haider**, [49] in 2013 conducted a study evaluating the shear bond strength between Ni-Cr and Co-Cr to porcelain. A stainless steel cylindrical matrix was used for the preparation of metal dies. Ten metal dies were made each of Ni-Cr and Co-Cr. The ceramic was then applied according to manufacturer's instructions. Shear tests were conducted in a universal testing machine and it was found that no difference was found between the shear strength of the two metal alloys.

- **K.Vijay Venkatesh et al**, [50] in 2013 did a review on Laser Welding using 13 other reference articles taken from PubMed. The review stated that laser welding is a good alternative to correcting misfits in implants, cast partial dentures and in ill-fitting crowns for correction. Reports also claimed on the good bond strength of laser welded segment to ceramics.

- **Suk-Ho Kang et al** [51] in 2013 The aim of this study is to compare flexural strength before and after heat treatment of two lithium disilicate CAD/CAM blocks, IPS emax CAD (Ivoclar Vivadent) and Rosetta SM (Hass), and to observe their crystalline structures. The study concluded that there were no statistically significant differences in flexural strength between IPS e.max CAD and Rosetta SM either before heat treatment or after heat treatment. For both ceramics, the initial flexural strength greatly increased after heat treatment, with significant differences. The FE-SEM images presented similar patterns of crystalline structure in the two ceramics. IPS e.max CAD and Rosetta SM showed no significant differences in flexural strength. They had a similar crystalline pattern and molecular composition.

- In 2013 **E.L. McGinley et al**, [52] studied the Influence of *S. Mutans* on Base-metal Dental Casting Alloy Toxicity. The exposure of base-metal dental casting alloys to the acidogenic bacterium Streptococcus mutans significantly increases cellular toxicity following exposure to immortalized human TR146 oral keratinocytes. Given the predominance of S. mutans oral carriage and the exacerbated cytotoxicity observed in TR146 cells following exposure to S. mutans-treated base-metal dental casting alloys, the implications for the long-term stability of base-metal dental restorations in the oral cavity are a cause for concern.

- In 2013 **Sulekha Gosavi et al**, [53] conducted a study to evaluate the dependence of bond strength of 100% fresh non-precious alloy and the combination of 50% recast (used) alloy and 50% fresh alloy with three different veneering ceramic material. To evaluate the shear bond strength between new and recast alloy nonprecious Ni-Cr alloy was used with three different commercially available ceramics. A total of 60 samples were prepared and divided in two groups depending on the new or recast alloy. The 30 specimens of new alloy (group A) and 30 specimens of recast alloy (group B) were fabricated. Each group was divided further into three subgroups of 10 specimens for ceramic veneering Vita VMK-95 [V], IPS Classic [I] and Noritake [N] as veneering ceramic materials. Thus, six subgroups were formed as groups AV, AI, AN, BV, BI and BN. Groups AV and BV were veneered with Vita Ceramics. The bond strength between new [group A] and recast alloy [group B] using three different veneering ceramics were evaluated and it was found that the new or the fresh alloy had highest shear bond strength than the recast alloy. It was found that there was significant difference in bond strength between the new and recast alloys, when same type of ceramics was compared. When comparing ceramics, the Noritake group had highest bond strength, while other groups, that is, Vita and Ivoclar had comparatively low bond strength. From this study, conclusion can be drawn that the use of 50% recast alloy shows reduction in bond strength values. Therefore, the use of recast alloy should not exceed more than 50%, as it would compromise the properties of alloy and the efficacy of bond strength between ceramic and alloy.

- **Horia Maoela et al**, [54] in 2013 did a study of the thermal expansion coefficient of a dental alloy type Co-Cr-Mo and its compatibility with a ceramic mass following thermal treatment according to the technological stages of production of a metal-ceramic prosthetic restoration. In the study three situations where observed comparing the differences between the linear thermal expansion coefficients in the analysed couples:

  a. The existence of a positive difference of the thermal expansion coefficients TEC (higher TEC of the alloy than the ceramic TEC), in which case the ceramics is compressed and the metal is under pressure, a case proven to be most prevailing in the metal-ceramic dental restorative systems.

  b. The existence of a positive difference of TEC (higher TEC of the alloy than the ceramic TEC), but with differences higher than the recommended average.

  c. The existence of a negative difference, the higher TEC ceramic than the alloy TEC, case in which the ceramic is under pressure and the metal is compressed.

  The author concludes by saying that further researches are needed in order to understand the various factors that influence the metal-ceramic bond.

- **Simel Ayyidiz et al**, [55] in 2013 conducted a study to evaluate the effect of annealing on the nanostructure and hardness of Co-Cr metal ceramic samples that were fabricated with a direct metal laser sintering technique. The results of fitting function presented that DMLS specimen annealed in Argon atmosphere were the most homogeneous product as the minimum bilayer thickness was measured. After the manufacturing with DMLS technique, annealing in argon atmosphere is an essential process for Co-Cr metal ceramic substructures. The author concludes by stating that dentists should be familiar with the materials that are used in clinic for prosthodontics treatments.

- **Youssef S et al**, [56] in 2014 reviewed the physio-mechanical properties of Co-Cr which are widely known for their biomedical applications in the orthopedic and dental fields. In dentistry, Co-Cr alloys are commonly used for the fabrication of metallic frameworks of removable partial dentures and recently have been used as metallic substructures for the fabrication of porcelain-fused-to-metal restorations and implant frameworks. The increased worldwide interest in utilizing Co-Cr alloys for dental applications is related to their low cost and adequate physico-mechanical properties. Additionally, among base-metal alloys, Co-Cr alloys are used more frequently in many countries to replace Nickel-Chromium (Ni-Cr) alloys. This is mainly due to the increased concern regarding the toxic effects of Ni on the human body when alloys containing Ni are exposed to the oral cavity. The review concluded that Co-Cr is a better alternative to Ni-Cr since it is more noble and biocompatible than Ni-Cr. Wironium alloy samples. Under the scanning electron microscope, the laser welded joints show uniform welding and continuous molt pool all over the surface with less porosity than the conventionally welded joints. Laser welding is an advantageous method of connecting or repairing cast metal prosthetic frameworks.

- **Priyanka Mahale et al**, [57] in 2014 evaluated the bond strength of ceramic to Ni-Cr alloy with recast alloy and found that upto fifty percent fresh alloy does not have a significant effect on the bond strength. fifty percent fresh alloy had better strength when compared to less than fifty percent.

- **Carlo et al**, [58] in 2014 did a review of intraoral laser welding in implant dentistry since; dental industry without lasers is inconceivable right now. This captivating technology has outlasted other possible alternative technologies applied in dentistry in the past due to its precision, accuracy, minimal invasive effect as well as faster operating time. Other alternatives such as soldering, spot welding, plasma welding, and single pulse tungsten inert gas welding have their pros and cons; nevertheless, laser welding remains the most suitable option so far for dental application. The literature review clearly states that laser assisted dental welding will continue to grow and will become an unparalleled technology for dental arena and found that laser welding can be done intra orally without any side effects

- **Jun Tae hong et al**, (59) in 2014 conducted a study to compare the bond strength of porcelain to millingable palladium-silver (Pd-Ag) alloy, with that of 3 conventionally used metal-ceramic alloys. Four types of metal-ceramic alloys, castable nonprecious nickel-chrome alloy, castable precious metal alloys containing 83% and 32% of gold, and millingable Pd-Ag alloy were used to make metal specimens. And porcelain was applied on the center area of metal specimen. The 3-point bending test showed the strongest metal-ceramic bond in the nonprecious Ni-Cr alloy, followed by millingable Pd-Ag alloy, precious metal alloy containing 83% of gold, and precious metal alloy containing 32% of gold. Nonprecious Ni-Cr alloy and precious metal alloy containing 32% of gold showed significant difference. The type of metal-ceramic alloys affects the bond strength of porcelain. Every metal-ceramic alloy used in this study showed clinically applicable bond strength with porcelain.

- **Kaleswara Rao et al**, (60) in 2014 conducted a study to compare the bond strength of nickel chromium (Ni-Cr) and cobalt chromium (Co-Cr) alloys with dental ceramic on repeated castings using shear bond test with a custom made apparatus. Significant reduction in the bond strength was observed with the addition of the first recast alloy compared with the addition of second recast alloy Ni-Cr alloys showed higher bond strengths compared to that of Co-Cr alloys. The addition of previously used base metal dental alloy for fabricating metal ceramic restorations is not recommended.

- **Shiva Alavi et al**, (61) in 2015 evaluated the effect of electric spot welding on the load deflection rate of stainless steel and chromium-cobalt orthodontic wires. Tukey test showed that there were significant differences between the load deflection rates of welded groups compared to control ones. Considering the limitation of this study, the electric spot welding process performed on stainless steel and chromium-cobalt wires increased their load deflection rates.

- **John Kokolis et al** (62) in 2015 conducted a study to evaluate the mechanical and interfacial characterization of laser welded Co-Cr alloy with two different joint designs. Dumbbell cast specimens were divided into 3 groups (R, I, K, n=10). Group R consisted of intact specimens, group I of specimens sectioned with a straight cut, and group K of specimens with a 45° bevel made at the one welding edge. The microstructure and the elemental distributions of alloy and welding regions were examined by an SEM/EDX analysis and then specimens were loaded in tension up to fracture. The tensile strength (TS) and elongation (ε) were determined and statistically compared among groups. The author concluded stating, that the K shape joint configuration should be preferred over the I, as it demonstrates improved mechanical strength and survival probability.

- **R. Prabhu et al**, [16] in 2016 conducted a study to assess the efficacy of metal-ceramic fixed dental prosthesis fabricated with DMLS technique, and its clinical acceptance on long-term clinical use. The study group consisted of forty-five patients who were restored with posterior three-unit fixed partial denture prosthesis made using direct laser sintered metal-ceramic restorations. Patient recall and clinical examination of the restorations were done after 6months and every 12 months thereafter for the period of 60 months. Clinical examination for evaluation of longevity of restorations was done using modified Ryge criteria which included chipping of the veneered ceramic, connector failure occurring in the fixed partial denture prosthesis, discoloration at the marginal areas of the veneered ceramic, and marginal adaptation of the metal and ceramic of the fixed denture prosthesis. Periapical status was assessed using periodical radiographs during the study period. Survival analysis was made using the Kaplan-Meier method. None of the patients had failure of the connector of the fixed partial denture prostheses during the study period. Two exhibited biological changes which included periapical changes and proximal caries adjacent to the abutments. DMLS metal-ceramic fixed partial denture prosthesis had a survival rate of 95.5% and yielded promising results during the 5-year clinical study.

- **Sven et al**, [6] in 2017 conducted a study to compare the degradation resistance of nickel-chromium and cobalt-chromium alloys used as a base material for partial dentures in contact with saliva. Wiron 99 and Wironit Extra-Hard were selected as representative casting alloys for Ni-Cr and Co-Cr alloys, respectively. The alloys were tested in contact with deionized water, artificial saliva and acidified artificial saliva. It was found that Co-Cr alloy was more stable than the Ni-Cr alloy in all solutions tested. Leaching of nickel and corrosion attack was higher in Ni-Cr alloy in artificial saliva compared with the acidified saliva. The corrosion resistance of the Co-Cr alloy was seen to be superior to that of the Ni-Cr alloy, with the former exhibiting a lower corrosion current in all test solutions. Microstructural topographical changes were observed for Ni-Cr alloy in contact with artificial saliva. The Ni-Cr alloy exhibited microstructural changes and lower corrosion resistance in artificial saliva. The acidic changes did not enhance the alloy degradation. Ni-Cr alloys are unstable in solution and leach nickel. Co-Cr alloys should be preferred for clinical use.

- **Tsanka Dikova et al**, (5) in 2017 conducted a study to investigate the fitting accuracy of Co-Cr dental bridges, manufactured by three technologies.. The four-part dental bridges of Co-C//r alloys were produced by conventional casting of wax models, 3D printing patterns followed by casting and selective laser melting. The marginal and internal fit of dental bridges was studied out by two methods – silicone replica test and CAD software. As the silicone replica test characterizes with comparatively low accuracy, a new methodology for investigating the fitting accuracy of dental bridges was developed based on the SolidWorks CAD software. The newly developed method allows the study of the marginal and internal adaptation in unlimited directions and high accuracy. Investigation the marginal fit and internal adaptation of Co- Cr four-part dental bridges by the two methods show that the technological process strongly influences the fitting accuracy of dental restorations. The internal gap values vary in different regions – it is highest on the occlusal surfaces, followed by that in the marginal and axial areas. The higher fitting accuracy of the bridges, manufactured by casting with 3D printed patterns and SLM, compared to the conventionally cast bridges is a good precondition for their successful implementation in the dental offices and laboratories.

- **Annu Eliza et al** (63) in 2018 conducted a study using 20 maxillary right canine typodont resin models. Tooth preparation was done with 1mm circumferential chamfer finish line, 1.5mm incisal height reduction, and a taper of six degrees with the help of a putty index. DMLS coping were fabricated over this and silicone replicas were made. The marginal accuracy was determined by using a microscope. Within the limit of this study, the marginal discrepancy of Co-Cr copings fabricated using DMLS, computer aided milling, traditional casting, and ringless casting were found to be within the range of clinical acceptance and can highly improve your production system. With the variety of 3D technologies the required metal printed parts can be designed and manufactured on compute.

# RELEVANCE

Metal Ceramic restorations are primarily used in dentistry because of their improved mechanical, biological and esthetic properties. Trial insertion of metal framework is critical to ensure adequate fit of Fixed Dental Prosthesis. When fit is inadequate, sectioning of framework followed by welding, may be done in order to seat the prosthesis precisely. However, the effect of it on the bond between ceramic and the metal alloy should be considered. Four mechanisms have been described to explain the bond between the ceramic veneer and the metal substructure.

1. Mechanical entrapment
2. Compressive forces
3. Van der waals forces
4. Chemical bonding

All these provide adequate bond of ceramic to the metal. But, studies considering these parameters are few in number and further research or study into this particular field is necessary to properly understand their outcomes.

Understanding the bond between the two, after welding once carried out, can establish the longevity of the same in a clinical scenario.

# METHODOLOGY

The study evaluated and compared the effect of Laser welding and spot welding on the micro-tensile bond strength of ceramic to laser sintered Co-Cr metal alloy

**MATERIALS USED IN THE STUDY**

- Co – Cr metal alloy - EOSINT M EOS CobaltChrome SP2
- DENTARUM Co-Cr Schweibraht welding wire
- Opaque Porcelain - Ivoclar IPS Classic Programat 300
- Ivoclar IPS Classic modeling liquid for mixing with the respective powders
- Dentin Porcelain - Ivoclar IPS Classic Dentin
- Enamel - Ivoclar IPS Classic Enamel

**ARMAMENTARIUM**

- CAD Software – AutoCAD® AutoDesk 2015
- CAD - CAM Software – CAMWorks® Solids SolidWorks©
- Direct Metal Laser Sintering Unit - EOS EOSINT M 270
- Laser Welder - EVO125 LASERXXS
- Spot Welder – LAMPERT PUK D2
- Ceramic Furnace - Ivoclar Vivadent Programat 3010
- Micro-Tensile Bond Strength Universal testing Machine – Fine Testing Machine – TFUN 400

The properties studied are:-

1. Micro-tensile bond strength without welding
2. Micro-tensile bond strength after laser welding
3. Micro-tensile bond strength after spot welding

## SAMPLING

The sample size (n) = 10, for each group, which was calculated using SPSS version 16. Total sample size of the study is 30.

The samples intended for conducting the study were calculated using the

formula:

$$n= 2 \text{ x } (Z_{\alpha} + Z_{\beta})^2 + (sd)^2 /d^2$$

where,sd is the Standard Deviation between the three groups, d is the Expected difference, alpha is alpha error – 5%, beta is power – 80%.

The sample size worked out from the above formula is 10, so each group consisting of 10 samples.

**Inclusion Criteria**:

- Direct Metal Laser Sintered blocks of Co-Cr metal alloy which are of size 5x5x5mm and not more or less than the specified size.
- Blocks of Direct Metal Laser Sintered Co-Cr metal alloy which are polished and do not have any rough surfaces.

**Exclusion Criteria**:

- Blocks of Direct Metal Laser Sintered Co-Cr metal alloy which are not polished or of ideal size.

**Sampling Procedure:**

The sample size for the study is 30. It is divided into 3 groups, each group consisting of 10 samples. The sample size was calculated using SPSS version 16.

10

| Group | Description | Sample Size |
|---|---|---|
| GROUP C | Metal-ceramic blocks without welding | 10 |
| GROUP S | Metal-ceramic blocks with Spot welding | 10 |
| GROUP L | Metal-ceramic blocks with Laser welding | 10 |

**PREPARATION OF CO-CR METAL ALLOY BLOCKS**

Two blocks were designed in the CAD-CAM software (AutoCAD® AutoDesk 2015), each with dimensions of 5x5x5mm. No design modifications were made on the first block. The second block was designed in order to in co-operate a groove within it that ran along a surface of the block with a depth of 1.5mm and width of 1mm. The first block was designed to produce blocks of the Control Group (C) and the second block was designed to produce blocks of Test Groups (L) and (S).

These designs were then recreated using the CAD-CAM software CAMWorks® Solids SolidWorks© and then transferred to the Metal Laser Sintering Unit Powdered Co – Cr metal alloy was loaded into the Direct Metal Laser Sintering Unit (EOS EOSINT M 270) and based on the CAD-CAM designs, 10 blocks of Control group (C) and 10 blocks each of test groups, Laser sintered (L) and Spot welded (S) were manufactured by Direct Metal laser Sintering, retrieved 6 hours later.

The retrieved blocks were finished and divided into 3 groups of 10 samples each:

A. Group C – Blocks without notches and without welding performed

B. Group S – Blocks with a groove of 1.5mm depth, which were to be Spot welded with a Dentarum Co-Cr Schweibraht welding wire

C. Group L – Blocks with a groove of 1.5mm depth, which were to be Laser welded with a Dentarum Co-Cr Schweibraht welding wire.

## PREPARATION OF WELDED SPECIMEN

The Laser Sintered blocks with the notch of groups L and S were separated to perform welding. Grooves within the blocks in Group S were filled with a Dentarum Co-Cr Schweibraht welding wire and Spot welded using Lampart PUK D2

Grooves within the blocks in Group L were filled with a Dentarum Co-Cr Schweibraht welding wire and Laser welded using EVO125 LASERXXS. The excess was trimmed and the blocks were finished and polished.

## LAYERING OF METAL BLOCKS WITH CERAMIC

Once welding was completed, porcelain of 2mm thickness had to be condensed onto the surface of both test and control blocks. All blocks of all 3 groups, C,S and L were readied for layering using

- Opaque Porcelain - Ivoclar IPS Classic Programat p300
- Ivoclar IPS Classic modeling liquid for mixing with the respective powders
- Dentin Porcelain - Ivoclar IPS Classic Dentin
- Enamel - Ivoclar IPS Classic Enamel

Microabrasion using 110µm Aluminium Oxide particles at 75 psi pressure [20] was done in order to roughen the layering surface of the metal blocks, on any one surface of the blocks in C group and the welded surface of the blocks in L and S group. Steam under pressure was used in order to wash the surfaces clean of any residue from the Aluminium Oxide particles.

Two layers of opaque porcelain followed by two layers of dentin and one layer of enamel porcelain had to be added. The ceramic powder to be veneered was dispensed on a wet plate, following which; each layer of ceramic is condensed onto the control and test specimens.

First coat powder of opaque porcelain, is mixed with Ivoclar IPS Classic modeling liquid on a glass slab as per manufacturer instructions and applied as wash opaque following which it is fired (Ivoclar Vivadent Programat 3010) at a temperature of 850°C.

The second layer of opaque is then mixed on a glass slab and layered on top of the wash opaque porcelain and re-fired.

Dentin Ceramic was used to make the bulk of the veneer followed by adapting of Enamel Ceramic.

This is then transferred to a Firing tray and sintered in a calibrated ceramic furnace (Ivoclar Vivadent Programat 3010) according to manufacturer's instructions.

Glazing of ceramic was not performed, to leave that rough surface for better grip while testing for micro-tensile bond strength.

**TESTING THE MICROTENSILE BOND STRENGTH**

Due to the small size of the prepared specimen, stock jigs of the Universal testing machine would not hold the blocks. Hence a custom jig that would be attached to the stock jigs of the universal testing machine was fabricated using aluminum. It had two screw heads to lock the specimen in place against large forces.

For testing of Micro tensile bond strength, a universal testing machine – Fine testing Machine – TFUN 400 was used in tension at a crosshead speed of 1mm/min. The maximum load at failure is then calculated using the formula

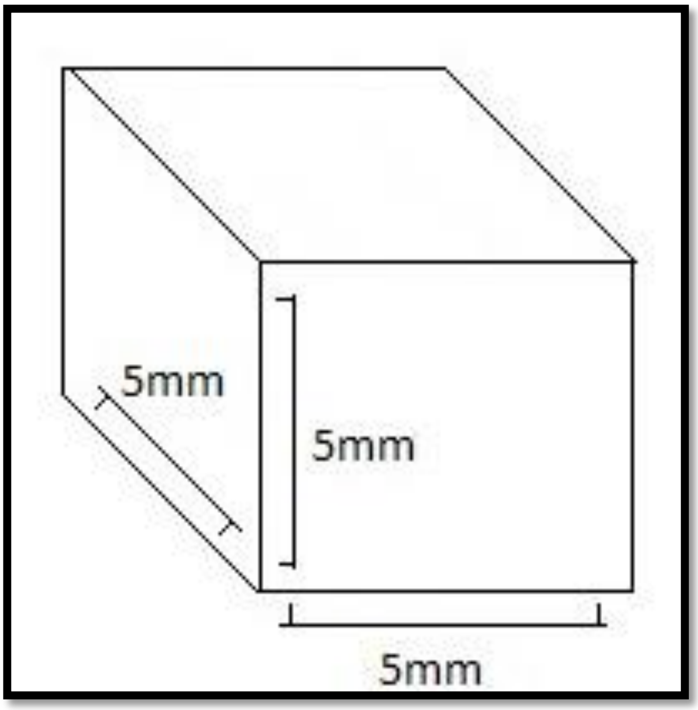
R=F/A

where R is the µTBS in MPa, F is the load at fracture in Newton (N) and A is the interfacial area in $mm^2$

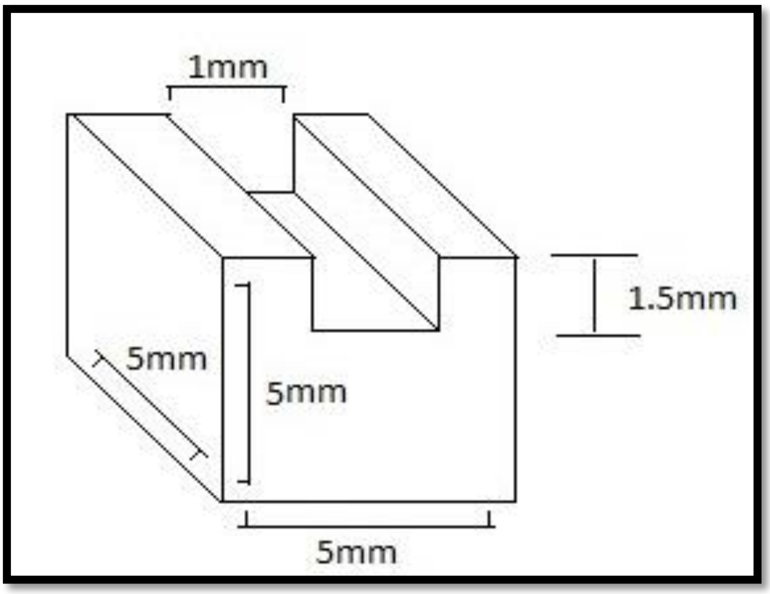
The data obtained were tabulated and analyzed statistically using ANOVA and Tukey hsd -post hoc analysis.

An ANOVA test is a way to find out if survey or experiment results are significant. In other words, they help to figure out if the null hypothesis has to be rejected or accept the alternate hypothesis. That is, testing groups to see if there's a difference between them. One-way or two-way refers to the number of independent variables present in the Analysis of Variance test. One-way has one independent variable with 2 levels and two-way has two independent variables. In this study, we have only one independent variable and hence One-Way ANOVA will be implemented.

Tukey's range test, also known as the Tukey's test, Tukey method, Tukey's honest significance test, or Tukey's HSD (honestly significant difference) test, is a single-step multiple comparison procedure and statistical test. It is used to find means that are significantly different from each other. Tukey's test compares the means of every treatment to the mean of every other treatment; that is, it applies simultaneously to the set of all pairwise comparisons and identifies any difference between two means that is greater than the expected.

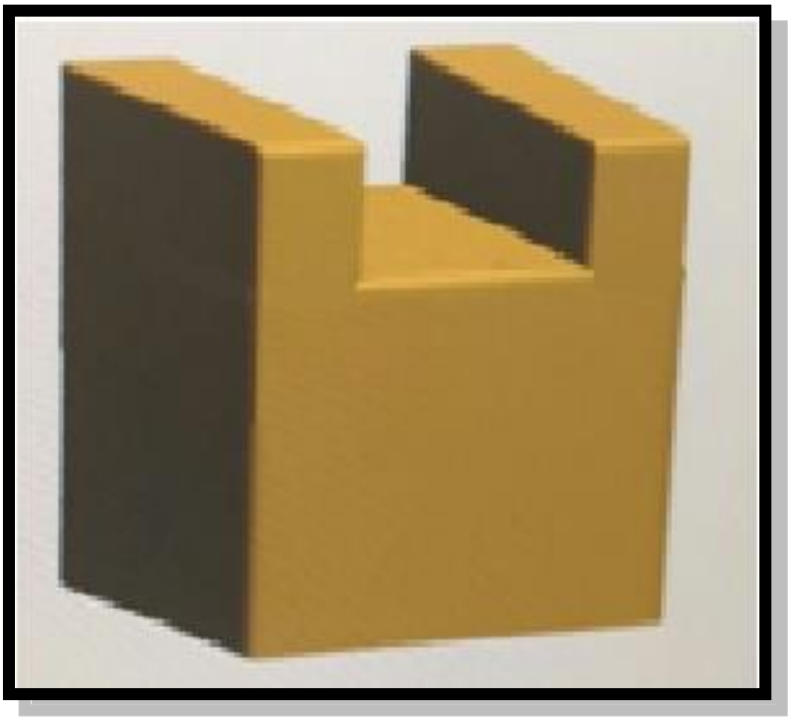



Block without groove - designed using AutoCAD® Autodesk 2015



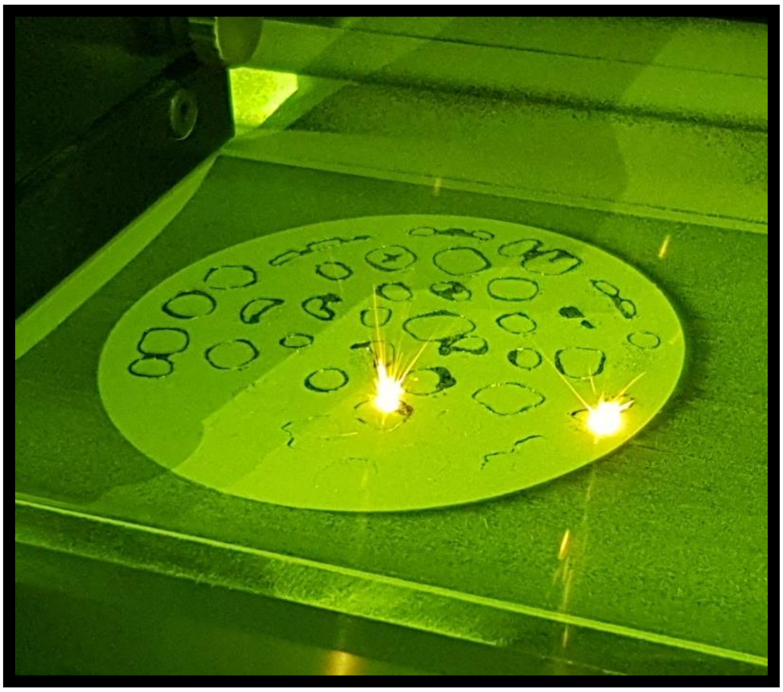

Blocks with groove in-cooperated - designed using AutoCAD® Autodesk 2015

Blocks without groove - designed with CAD-CAM software CAMWorks® Solids SolidWorks©



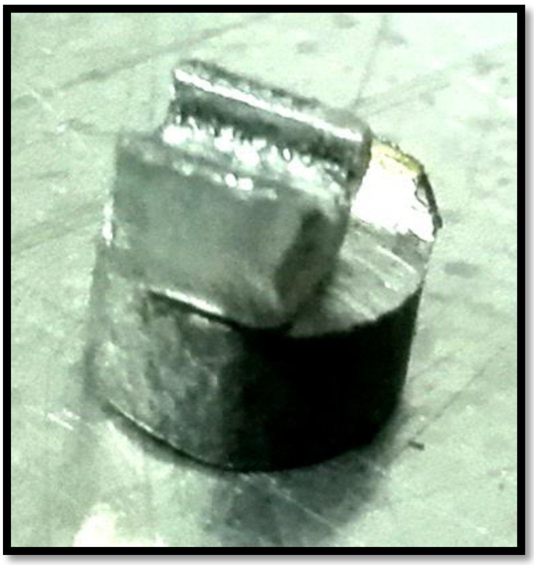
Blocks with groove - designed with CAD-CAM software CAMWorks® Solids SolidWorks©


Direct Metal Laser Sintering Unit - EOS EOSINT M 270



Direct Metal Laser Sintering on Co-Cr alloy powder

DMLS Co-Cr metal alloy blocks without groove

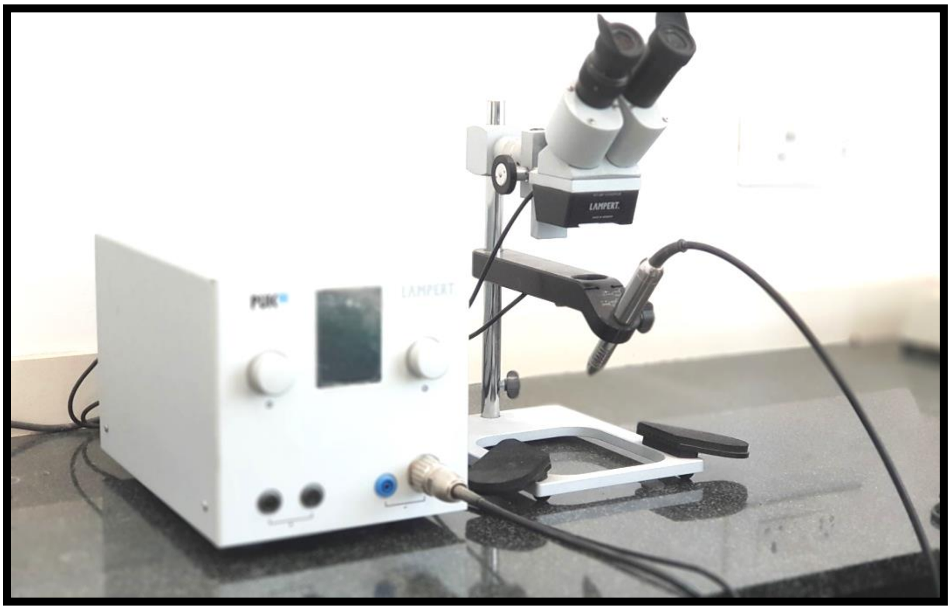


DMLS Co-Cr metal alloy blocks with groove

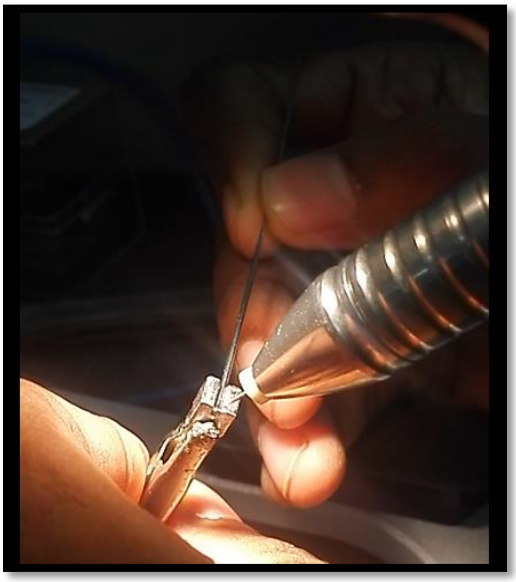

Laser Welder - EVO125 LASERXXS


Laser Aperture with nozzle for Cutting Gas

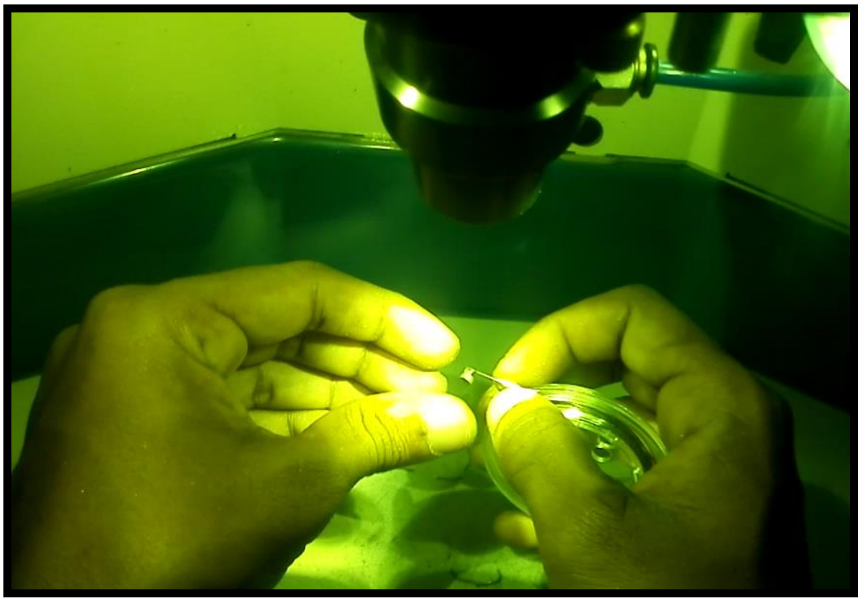

DENTARUM Co-Cr Schweibraht welding wire




Spot Welding unit - LAMPERT PUK D2



Spot welding

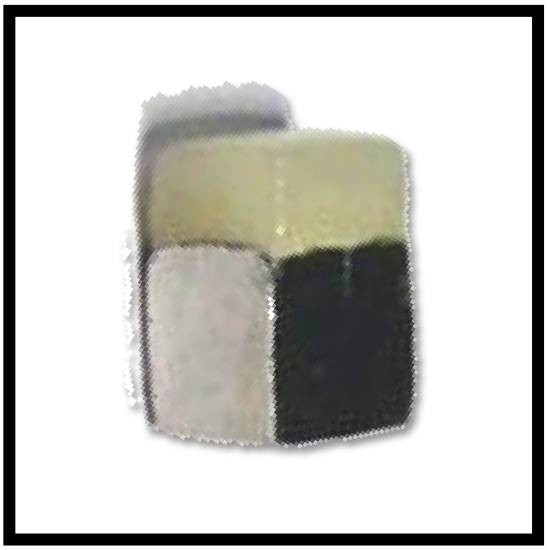


Laser welding


Ivoclar IPS Classic Opaque, Dentin and Enamel

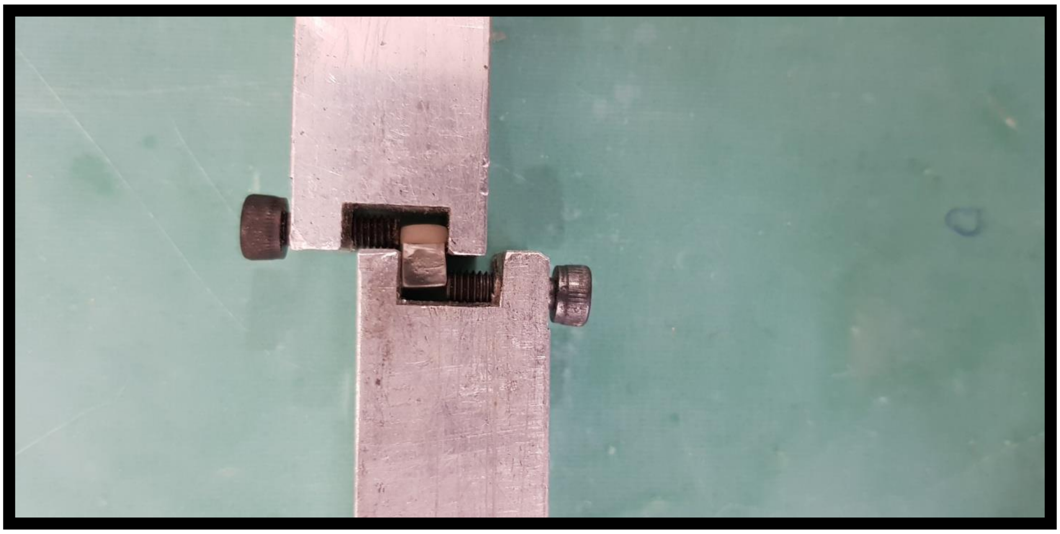

Ceramic Furnace - Ivoclar Vivadent Programat 3010

DMLS Co-Cr metal alloy blocks after layering with ceramic with a thickness of 2mm



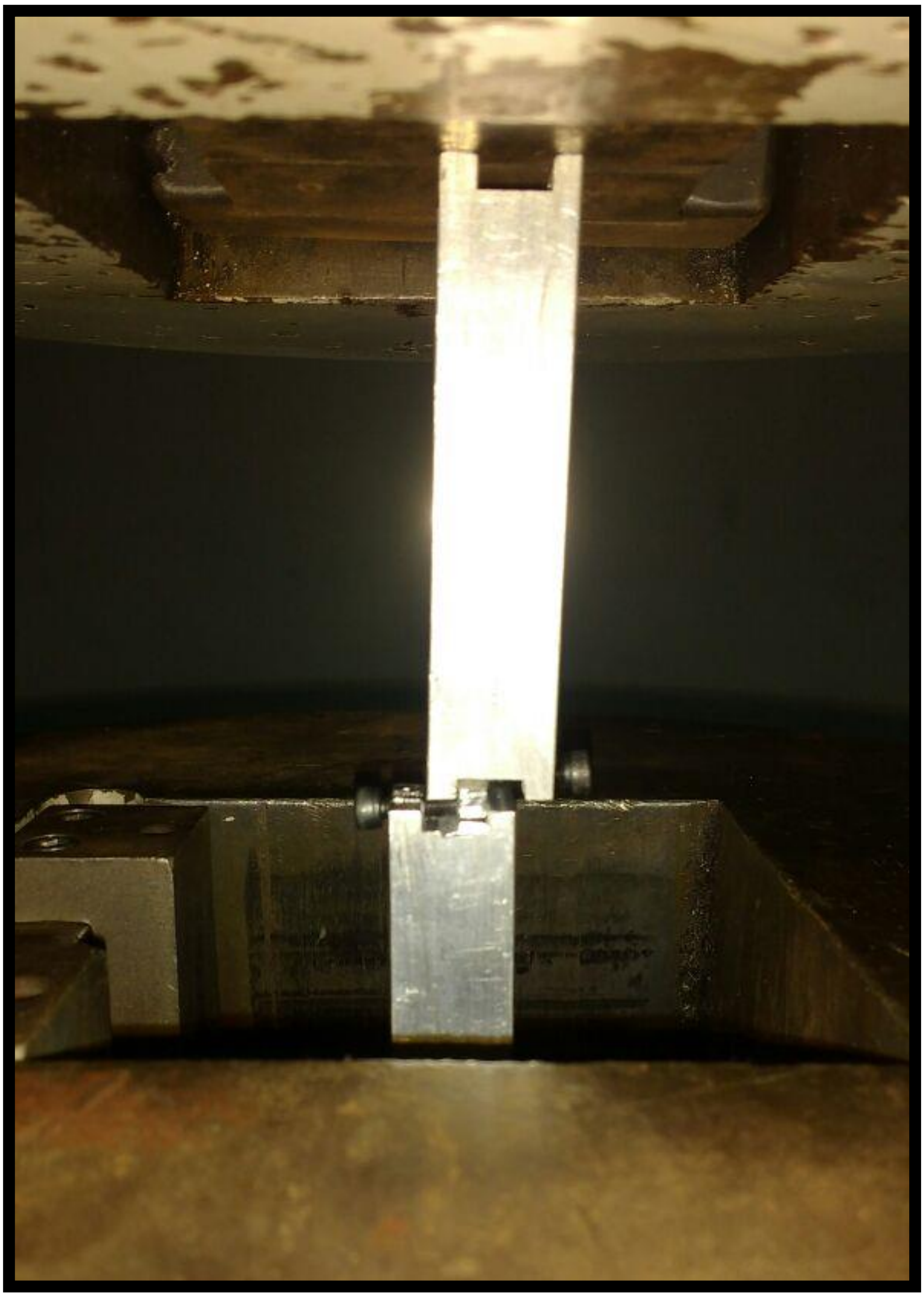
DMLS Co-Cr metal alloy blocks after finishing and polishing

Custom made aluminum jigs



Blocks to be tested within the aluminum jigs

Fine Testing Machine – TFUN400



Testing the micro-tensile bond strength on the Universal testing machine

Fractured specimen

# RESULTS

In this section, the results of the data analysis are presented. The data was collected and then processed in response to the problems posed in the objectives and aims of this dissertation. None of the blocks had any premature bond failures. The micro-tensile bond strength tested was significantly different from the blocks that were not laser welded or spot welded against those that were. The individual fracture loads of the Control group, Laser welded group and Spot welded groups were tabulated individually.

**Hypothesis testing**

To verify the data derived from the test, statistical tests for hypothesis testing – ANOVA test and Post – Hoc test are performed. The micro-tensile bond strength of individual specimen were determined and calculated using the previously mentioned formula.

**Null Hypothesis**

Laser welding and Spot welding would not create a difference on the bond strength between ceramic and DMLS Co-Cr metal alloy.

**Alternate Hypothesis**

Laser welding and Spot welding would decrease the bond strength between ceramic and DMLS Co-Cr metal alloy.

Level of significance, $\alpha=0.05$.

**Table 1 - Micro-tensile bond strength of control group**

| Sample Identification | Specimen Number | Ultimate Tensile Load, N | Tensile Strength, $N/mm^2$ |
|---|---|---|---|
| Control Group | T-1 | 560 | 24 |
| | T-2 | 580 | 25 |
| | T-3 | 560 | 24 |
| | T-4 | 570 | 24 |
| | T-5 | 580 | 25 |
| | T-6 | 560 | 24 |
| | T-7 | 580 | 25 |
| | T-8 | 550 | 23 |
| | T-9 | 580 | 25 |
| | T-10 | 580 | 25 |

**Table 2 - Micro-tensile bond strength of laser-welded group**

| Sample Identification | Specimen Number | Ultimate Tensile Load, N | Tensile Strength, N/mm$^2$ |
|---|---|---|---|
| Laser – Welded | T-1 | 520 | 22.6 |
| | T-2 | 550 | 23.9 |
| | T-3 | 510 | 22.2 |
| | T-4 | 510 | 22.2 |
| | T-5 | 530 | 23.1 |
| | T-6 | 520 | 22.6 |
| | T-7 | 500 | 21.7 |
| | T-8 | 550 | 23.9 |
| | T-9 | 510 | 22.2 |
| | T-10 | 520 | 22.6 |

**Table 3 - Micro-tensile bond strength of spot-welded group**

| **Sample Identification** | **Specimen Number** | **Ultimate Tensile Load, N** | **Tensile Strength, $N/mm^2$** |
|---|---|---|---|
| Spot - Welded | T-1 | 520 | 22.1 |
| | T-2 | 540 | 22.9 |
| | T-3 | 530 | 22.5 |
| | T-4 | 520 | 22.1 |
| | T-5 | 550 | 23.3 |
| | T-6 | 540 | 22.9 |
| | T-7 | 530 | 22.5 |
| | T-8 | 570 | 24.2 |
| | T-9 | 550 | 23.3 |
| | T-10 | 530 | 22.5 |

Where,

- T stands for Test specimen.
- N stands for Newton.
- $N/mm^2$ stands for Newtons per millimetre square.

The micro-tensile bond strength was calculated from the received Ultimate Tensile strength using the formula,

$$R=F/A$$

where R is the µTBS in Mpa, F is the load at fracture in Newton (N) and A is the interfacial area in $mm^2$

Based on the values that were tabulated, the mean and standard deviation were was tabulated.

**Table 4 - Difference in the micro-tensile bond strength between the three groups**

| Group | Mean | SD | P VALUE |
|---|---|---|---|
| Laser welded | 22.7 | 0.7318 | 0.0001* |
| Spot welded | 22.83 | 0.6429 | |
| Blocks without groove | 24.4 | 0.6992 | |

*P<0.05 is statistically significant

**<u>Inference</u>**:- There is a decrease in the micro-tensile bond strength between Co-Cr metal alloy and ceramic after Spot welding and Laser welding.

**Table 5 - Summary of One Way ANOVA**

| Source of variation | Sum of squares | Degree of freedom | VARIANCE | F | P |
|---|---|---|---|---|---|
| Between groups | 17.906 | 2 | 8.953 | 18.681 | 0.0001* |
| Within groups | 12.939 | 27 | 0.479 | | |
| Total | 30.845 | 29 | | | |

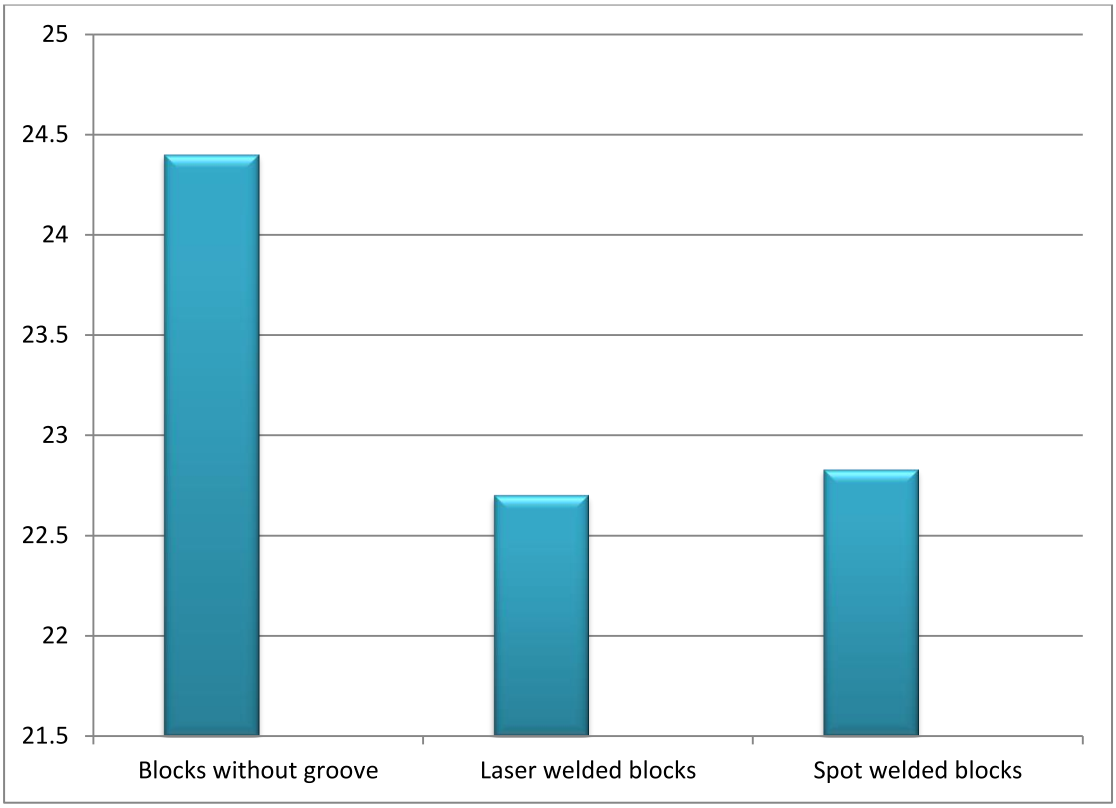
**<u>Inference</u>:-** The table shows that there is a statistically significant difference in the micro-tensile bond strength between Co-Cr metal alloy and ceramic after spot welding and laser welding.

**Table 6 - Tukey HSD -POST HOC analysis**

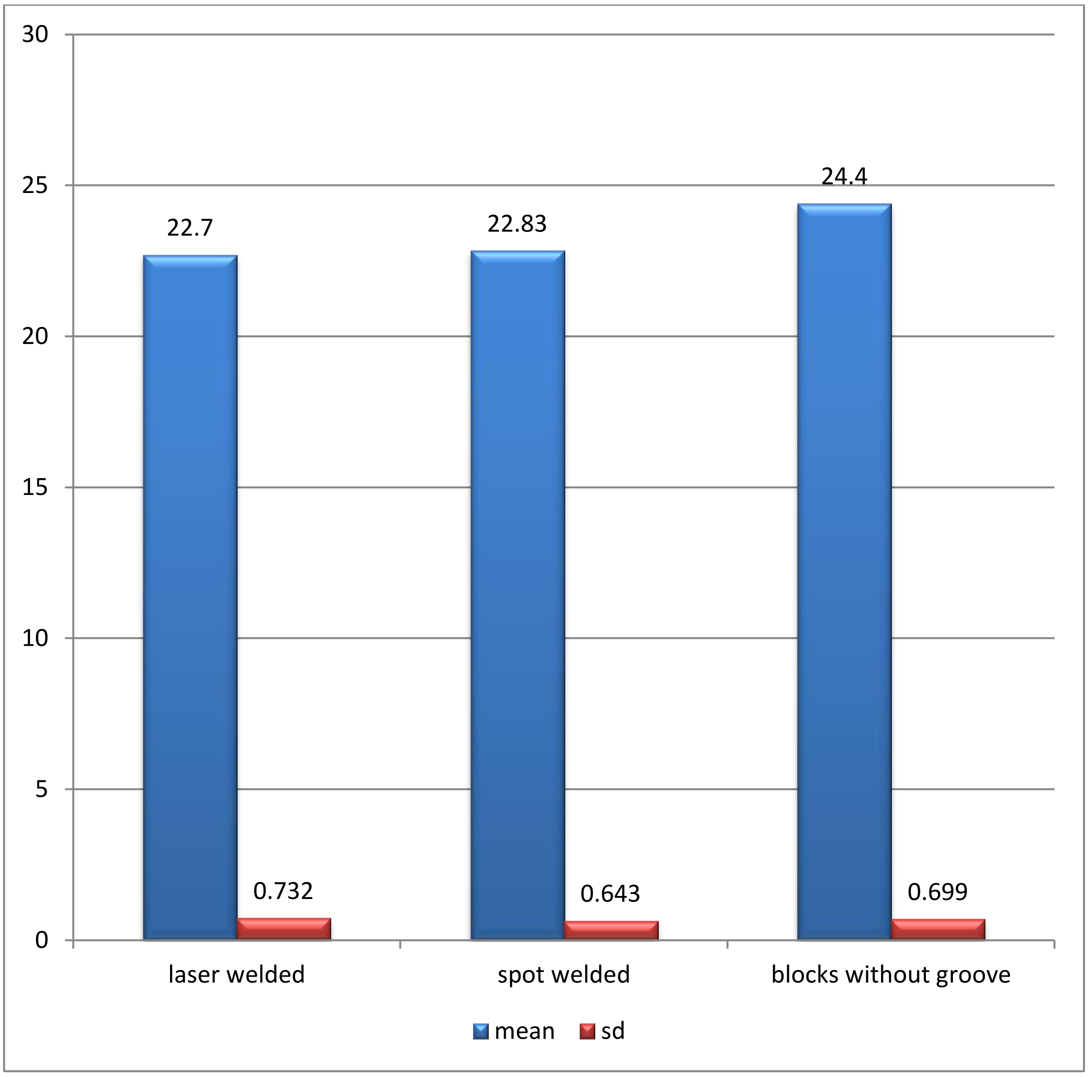
| SPECIMEN | DIFFERENCE | CONFIDENCE INTERVAL | P VALUE |
|---|---|---|---|
| Laser vs spot welded blocks | 0.1300 | -0.6376 to 0.8976, | 0.9077 |
| Laser welded vs block without groove | 1.7000 | 0.9324 to 2.4676 | 0.0000 |
| Spot welded vs block without groove | 1.5700 | 0.8024 to 2.3376 | 0.0001 |

**<u>Inference</u>**:- The table shows that there is a statistically significant difference in the micro-tensile bond strength between Co-Cr metal alloy and ceramic within the spot welded and laser welded groups, spot welded and control group and laser welded and control group.

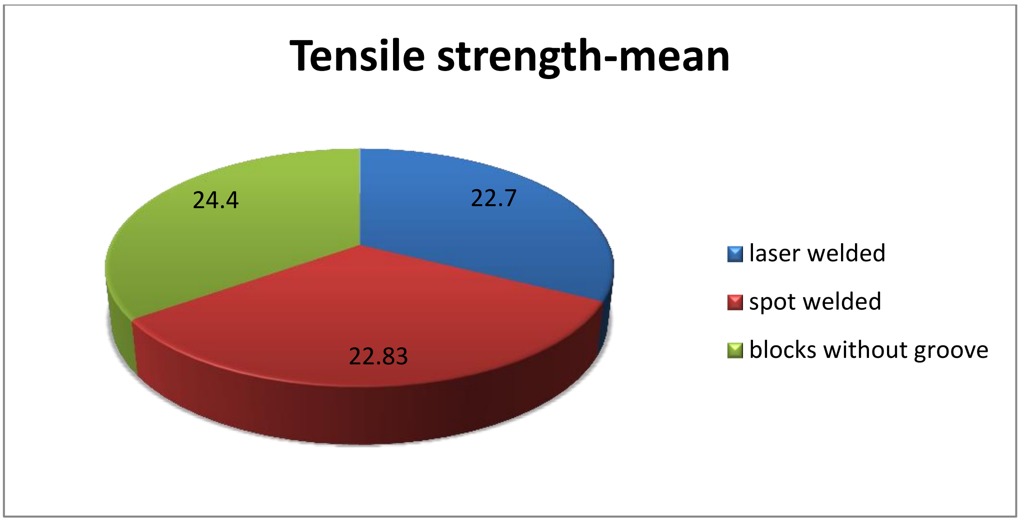
**Graph 1- Difference in the Micro-tensile bond strength between the three groups**

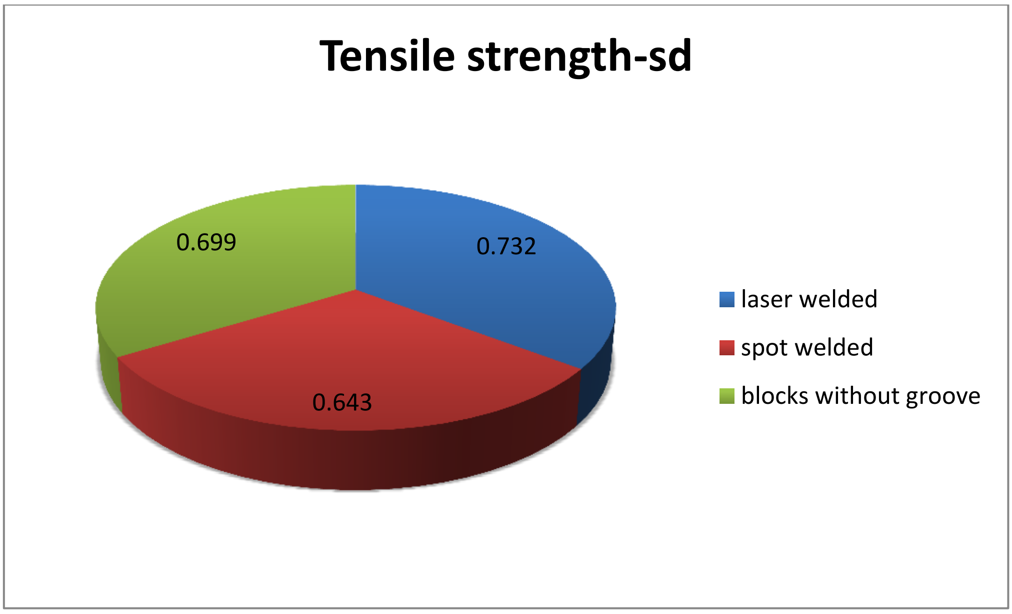


**Graph 2- Comparison of tensile strength**




**Inference**:- The graph shows that the control blocks had the highest micro-tensile bond strength.




**Inference**

The result has shown that laser welding or spot welding significantly reduced the micro-tensile bond strength between ceramic and Direct Metal Laser sintered Co-Cr metal alloy.

# DISCUSSION

Fixed partial dentures (FPDs), or more recently known as Fixed Dental Prostheses (FDPs) are "dental prostheses that are luted, screwed, or mechanically attached or otherwise securely retained onto natural teeth, tooth roots, and/or dental implant abutments.". During the past few decades, many types of FPDs have been used to replace missing teeth. The most common type of bridge used today by dentists is the PFM bridge. The alloys used are most commonly a noble metal combination of palladium and silver or high palladium or base metal alloys. Other metals used, include a high noble of gold-platinum, or gold-palladium, or gold-palladium and silver. A classification system provided by the American Dental Association based on the noble metal content divides the classes into high noble (60% with at least 40% gold), noble (25%), and predominantly base metal (less than 25% noble).[64] Long span dental bridges have been prone to misfits and difficulties in marginal accuracies. Hence, they have been cut and soldered/welded in the past to prevent rocking of the restoration and maintain good stability of the prosthesis for better adaptation and marginal integrity [18], [63], [65].

Several metal alloys have been employed for use in dentistry for the replacement of missing teeth. Gold is the oldest dental restorative material, due to its availability in nature and excellent biocompatibility properties; it has been used for dental repairs for more than 4000 years. These early dental applications were based primarily on aesthetics, than masticatory ability. The early Phoenicians used gold wire to bind teeth, and consequently, the Etruscans and then the Romans introduced the art of making fixed bridges from gold strip. The high malleability and ductility made it the easiest metals to be exploited in all forms. During the middle ages these techniques were lost, and only rediscovered in a modified form in the middle of the nineteenth century. The use of gold in dentistry remains significant today, and has an annual consumption typically estimated to be approximately 70 tonnes worldwide [1], [2]. However, gold isn’t cheap and with an increasing range of alternative metal alloys being available for dental repairs and processing aesthetic requirements which are biocompatible and satisfactory for the patient gold is being less popular in the field of dentistry. These metals have excellent strength and longevity for use as dental bridges or crowns.

Ceramics are another alternative material of choice in the field of dentistry for fixed bridges. But, their high cost is a factor that has to be accounted for. Using a base metal alloy sub-structure for the bonding of ceramics provided excellent aesthetics and brought the costs down to an acceptable level wherein it was more available to the common public. The most commonly used base-metal alloys are Ni-Cr and Co-Cr [(45), (58)]. Nickel–chromium alloys were first patented by Albert Marsh and is the oldest documented form of resistance heating alloy. It generally consists of 80% nickel and 20% chromium, by mass, but several alloy combinations have been formulated. Ni-Cr is silver-grey in color, is corrosion-resistant and has a high melting point of around $1400^{o}$C. Ni-Cr first gained importance in the 1930s due to the high cost of gold. Ni-Cr alloys have good properties for use with ceramics. The hardness and elastic modulus of the Ni-Cr alloy allows for the use of a thinner cross-section of material; the thinner cross-section provides more space for porcelain veneering while still offering good resistance. Ni-Cr is especially known for their high mechanical strength and high creep strength [(72)]. Another advantage is that their linear thermal expansion coefficient is similar to that of veneering porcelain. The similarity in thermal expansion reduces the risk of cracks and fractures during processing. Nickel sensitivity could be a concern with these alloys. The patient's sensitivity to nickel must be carefully and thoroughly evaluated before selecting these alloys.

Cobalt-chrome or cobalt-chromium (Co-Cr) is a metal alloy containing cobalt and chromium. Generally, Co-Cr alloy contains Cobalt - 27 to 30%, Chromium - 5 to 7%, Molybdenum and other important elements such as manganese and silicon. It also consists of traces of Carbon, Nitrogen, Sulfur, Tungsten, Phosphorous,etc. Co-Cr, alloy was discovered by Elwood Haynes in the early 1900s by fusing cobalt and chromium. The alloy was first discovered with many other elements such as tungsten and molybdenum within it. Haynes reported that his alloy was capable of resisting oxidation and corrosive fumes and exhibited no visible sign of tarnish even when subjecting the alloy to boiling nitric acid.[(6),]. Co-Cr alloy has been used in various fields where high wear-resistance is needed including aerospace industry manufacture of cutlery, bearings, blades, etc. Co-Cr alloy started receiving more attention once its biomedical application was found. In the 20th century, the alloy was first used in manufacturing of medical tools, and in 1960, the first Co-Cr prosthetic heart valve was implanted, which happened to last over 30 years thus proving that Co-Cr metal alloy has exceptionally high wear resistance.

Recently, due to excellent resistant properties, biocompatibility, high melting points, and incredible strength at high temperatures. Co-Cr alloy is used for the manufacture of many artificial joints which included hips and knees, dental partial bridge work and many others. The use of Co-Cr-based alloys for metal ceramic applications was first mentioned in the 1959 Weinstein patent for dental porcelain. Cobalt-chrome due to its high specific strength is also commonly used in dental implants, and orthopaedic implants. [72]

Several jurisdictions convict the use of different metal alloys over the other. In recent years, the use of alternative alloys such as titanium and Co-Cr ones has increased. However, the choice of base-metal alloy for prostheses differs around the world. Some countries use nickel-chromium (Ni-Cr) alloys with or without beryllium (Be), Co-Cr is the alloy more widespread in Europe and Japan; alloys containing more than 1% nickel are not used due to its allergic possibilities. The metal base alloys are inherently less expensive than those based on gold. Moreover, studies have shown that the bond strength of porcelain to base-metal alloys may be equal, or greater than, the bond strength to high-noble alloys. But they also have a number of disadvantages:

- The fusion and casting temperatures are appreciably higher than those of precious-alloys this makes it difficult to manipulate these alloys in the laboratory;
- Different casting methods must be employed,
- The process is more knowledge-based than traditional one. The formation of heavy oxides on the surface of the framework complicates welding and fusing of dental ceramics to the structure. Fusing porcelain to a base-metal alloy is more technique-sensitive than fusing porcelain to a noble metal alloy, in vitro.

Co-Cr has emerged as a better alternative to other metal alloys for use in dental bridges. Ni-Cr has always been the metal alloy of choice due to its better bond with ceramic as compared to Co-Cr using fresh alloy or recast alloy, although recast alloy always reduces the bond strength between ceramic to metal alloy. S.Gosavi stated that if recast alloys are used, their content should not be over 50% since the bond strength dips considerably once the concentration of recast alloy is more than 50% [53]. Haider et al conducted a study in 2013 comparing the shear bond strength between Ni-Cr and Co-Cr to porcelain and found no significant difference in the shear bond strengths between the two alloys stating that both of them had clinically acceptable bonding to porcelain [(49)]. Ni-Cr has shown lower color stability when compared to Co-Cr. Also allergy to Nickel is not a silenced fact. Nickel is an important cause of allergic contact dermatitis (ACD) in the general population, both among children and adults, with a worldwide prevalence of around 8.6%. The prevalence among young females is even higher, around 17%. [(19)]

Due to its increasing worth, excellent biocompatibility and good bond to ceramic, Co-Cr was selected as the material of choice for this study.

Co- Cr used in dentistry is typically made either using the conventional technique or by Direct metal laser sintering (DMLS). The Co-Cr metal alloy used in the study was EOS CobaltChrome SP2. The composition of which was: -

| | |
|---|---|
| Co: 61.8 – 65.8 wt-% | W: 4.9 – 5.9 wt-% |
| Cr: 23.7 – 25.7 wt-% | Si: 0.8 – 1.2 wt-% |
| Mo: 4.6 – 5.6 wt-% | Fe: max. 0.50 wt-% |
| Mn: max. 0.10 wt-% | |

Where, Co is Cobalt, Cr is Chromium, Mo is Molybdenum, W is Tungsten, Si is Silicon, Fe is Iron and Mn is Manganese.

Direct Metal Laser Sintering (DMLS) gives excellent reproduced specimens. With the accuracy obtained from a CAD-CAM software after scanning the cast, the produced specimen are always better than conventional casting techniques [(77)]. However some researchers did not find a significant difference between conventional casting and Laser Sintering claiming that although the amount of marginal fit was overall better for Laser sintered blocks, the difference wasn’t by a huge margin. Moreover, 3D printed patterns produced greater accuracy once they were made using Laser Metal Sintering. The long-term success of crowns and fixed partial dentures on natural teeth and implants depends on several variables, including but not limited to the accuracy of fit between castings and abutments and teeth, impression materials and techniques, material manipulation, casting and finishing processes and soldering. With conventional castings, the fit depends on the accuracy of the impression and the master production, expansion and contraction associated with the phases of the process [(9), (13), (55)]. R Prabhu et al [(16)] claimed a survival rate of 95.5% for FPDs that were fabricated using DMLS. Similarly, a study conducted by Y Ucar et al [(8)] concluded that conventionally cast FPDs had a survival rate of 90%. L Denti et al [(79)] stated that Cr-Co specimens produced by DMLS show excellent strength and absence of defects with respect to traditional casting. The cause for this being that DMLS process could guarantee a better repeatability, because in repeated specimens defects were not found. DMLS showed to produce parts more strong and rigid with respect to the casting process. Therefore, at least at a theoretical level, they present excellent characteristics of affinity with the aesthetic ceramic material that covers the fixed prosthesis, since the strain modes of the two materials are quite similar [(9), (10)]. The heating treatment, in the case of the sintered specimens, further increases the tensile strength while it causes a strong decrease in the value of percent elongation.

The process of welding helps join two sections of metal once they are cut. The concern in the field of dentistry is that it may have an effect on the bond strength between the metal and porcelain. This effect could be a positive effect or a negative effect. The welded area all though is a small area; it could be the point of propagation of a crack or cause of a weak substructure within the metal framework. Two welding processes were utilized in this study, namely, Laser welding and Spot welding.

Laser (Light Amplification by Stimulated Emission of Radiation) welding is one of the most technically advanced forms of welding. Its applications span across a diverse array of industries from aerospace to fine jewellery making. However, it was only in 1967 that we first used laser for its welding and cutting capabilities. The laser used in the 1967 experiments used oxygen assisted gas with a concentrated $CO_2$ laser beam [(85)]. Laser welding uses a highly concentrated beam of light on a very tiny spot so that the area under the laser beam absorbs the light and becomes highly energetic. As powerful laser beams are used, the electrons in the area get excited to a point where the material melts as a result of the atoms breaking bonds witheach other. This melting of the two materials at their seams fuse them into a joint. It is surprising how light can be powerful enough to melt metals within milliseconds. To achieve such powerful laser beams, the laser welding machine uses several parts that direct and amplify the laser.

Normally, the laser beam is supplied to the laser welding machine by the use of optical fibers. There are single fiber welding machines and there are multiple fiber welding machines. The multiple fiber welding machines have a laser connected to each fiber, with each fiber, the strength of the laser increases. To concentrate the beam to a point before it leaves the machine, a collimator lens in conjunction with a focusing lens is often used. The laser nozzle is always accompanied with another nozzle that supplies a gas which is called Process Gas or Cutting Gas.

Basically, it is the flow of gas, which is most commonly $CO_{2,}$ which is also directed towards the weld location with an aim to prevent the contact of the weld surface with the atmosphere. Without the use of cutting gas, there are only two options for weld atmosphere – Either normal atmosphere or vacuum. Laser welding in a vacuum is certainly possible, but not plausible because of its high cost and the requirement for a specialty setup.

In a normal atmosphere, laser welding without processing gas can yield unfavorable effects. Since nitrogen in the air is in very high concentration, it can mix with the molten metal and cause the formation of voids or holes within the weld. Such occurrences can lead to weld failures.

Factors like humidity in the air can cause the production of hydrogen when welding. The diffusion of hydrogen into the metal also leads to weak weld joints. Hence laser welding in a normal atmosphere without shielding is not entertained at all. Weld machines come with a cutting gas attachment that shoots gas to the weld surface making sure that no impurities are mixed with the weld.

**Types of laser welding**

Laser welding can be done in two ways – Heat conduction welding and keyhole welding.

*Heat conduction welding:* In this process, the metal surface is heated above the melting point of the metal, but not to an extent that it vaporizes. This process is used for welds that do not need high weld strength.

The advantage of hot conduction welding is that the final weld will be highly smooth and aesthetical. Low power laser in the range of <500W is used for heat conduction welding.

*Keyhole welding:* In this process, the laser beam heats up the metal in such a way that the contact surface vaporizes, digging deep into the metal. This creates a keyhole where a plasma-like condition is created with temperatures rising well above 10,000K. This process required high powered lasers with power above 105W/mm2. (81)

Heat conduction Laser welding was implemented in this study. It used Nd:YAG Laser at 1064nm at a voltage of 230V and spot diameter of 1mm was used.

Electric spot welding was carried out using a Lampert PUK D2, done twice at 30W to join the two sides of the metal. The process involves applying pressure and heat to the weld area using alloy copper electrodes which convey an electrical current through the weld pieces. The material melts, fusing the parts together at which point the current is turned off and pressure from the electrodes is maintained and the molten "nugget" solidifies to form the joint.

Studies show that the accuracy and strength of Laser welded metal parts are higher than those that were spot welded or soldered [(77), (87)], probably owing to the fact that, Lasers are able to produce more heat at a precise point and at a higher accuracy. Laser welding is said to be one of the best fusion-welding techniques for welding using dissimilar alloys.

Laser welding is a captivating technology that has outlasted several other technologies that were applied in dentistry due to its precision that it can be adjusted to a minimum of 0.2mm diameter spot. Barbosa et al [(14)] compared the clinical fit between UCLA abutments and implants used in frameworks of five elements that were cast in one piece after laser welding. Three different materials were used: titanium CP (grade 1), Co-Cr alloys, and Ni-Cr-Ti alloys. The passive fit of the frameworks was evaluated by testing the single screw and the stresses generated around the implants, by means of photoelasticity and found that there was a statistically significant improvement in the frameworks fit for all materials after sectioning and laser welding.

Material selection and clinical recommendations on ceramic bonding are based on mechanical lab tests that show great variability in materials and methods. One of the most common testing methods is the shear bond test. Tensile bond strength is the maximum stress that the material will with stand before rupture. The bond strength in this study was determined by the tensile mode of testing. Tensile strength provided information on the ultimate strength properties in tension. Bates and Smith (1965) [66] and Kawano F(1992) [67] considered tensile test was a good method of investigating bond strength, because it gives information on strength of the bond in comparison to tensile strength of the material. However the specific fracture pattern in shear testing may cause cohesive or adhesive failure patterns in the substrate that may lead to erroneous interpretation of the data while in micro-tensile tests, stress distribution was reported to be more homogeneous [68]. Moreover, clinical relevance would only pertain to metal and ceramic being of a smaller size. Hence, for this reason, micro-tensile test was employed in this study.

Thirty Co-Cr metal alloy blocks of size 5x5x5mm were Laser sintered using DMLS. Ten of which were involved in the control group and ten each in Group L – Laser welded and Group S – Spot welded. The blocks in Group L and S had a groove of depth 1.5mm and width 1mm running throughout the length of one surface of the block. The grooves were welded using a DENTARUM Co-Cr Schweibraht welding wire. These blocks were then sandblasted and cleaned using steam under pressure. Co-Cr Schweibraht welding wire. Sandblasting increases the surface area of contact, increases surface energy and increases wettability to porcelain [72], IPS Classic from Ivoclar Vivadent was the porcelain material of choice. 2 layers of opaque porcelain was fired onto the surface of the blocks followed by two layers of dentin and one layer of enamel porcelain were added.

Due to the small size of the prepared specimen, custom jigs had to be fabricated to hold them onto the Universal testing machine (Fine Testing Machine - TFUN400). Blocks were subject to tensile strength tests and the fracture loads were tabulated.

The results showed that the specimens which were spot welded showed marginally better µTBS probably owing to the fact that electric spot welding increases load deflection rate of Co-Cr alloys. [27]

Baba N et al [22] conducted a study assessing the mechanical strength of laser welded Co-Cr alloy and concluded that it could have a negative effect on the strength of Co-Cr alloy. Youssef S et al [56] in 2014 stated that Co-Cr should be more widely used in dentistry compared to Ni-Cr since Co-Cr is more biocompatible than Ni-Cr and since there is an increase in concern of Nickel toxicity among the general population, Co-Cr is a better material of choice for use as dental alloys. He also stated that Laser welding is a sustainable and viable option to proceed with since laser welding produced melted joints that were less porous than compared to conventional casting and uniform with continuous molten pools.

Leaching of metal ions occurs in an acidogenic environment which causes cytotoxicity. McGinley et al, [52] conducted a study by treating Ni-Cr and Co-Cr with S.mutans. Post treating, the acidogenic nature was greatly increased. This led to increased leaching of metal ions from both Ni-Cr and Co-Cr metal alloys when compared to untreated Ni-Cr and Co-Cr metal alloys. The metal ions leached from S.mutans treated Ni-Cr metal alloy was higher than when compared to S.mutans treated Co-Cr metal alloy, which on a long term, intra-orally could be a cause for concern.

Min-Ho Hong et al conducted a study owing to the high toxicity and low biocompatibility of Ni-Cr metal alloys. He compared the difference in biocompatibility of conventionally cast Ni-Cr alloy and Ni-Cr cast using DMLS and found that the blocks that were cast using DMLS had more homogenous dispersion of Ni-Cr metal alloyand finer grain formation [11]. Immersion tests studied the effect of ion release of Ni-Cr alloy by testing in a water-soluble tetrazolium salt assay and showed less leaching of ions as compared to conventionally cast alloy.

IPS Classic from Ivoclar Vivadent which is a feldspathic ceramic, was used in the study. This material was first introduced in 1989 and has proven over time to be a dependable dental material of choice.

The composition of IPS Classic Dentin, Intensive Dentin, Incisal, Opal Incisal, Transparent is as follows: -

| Standard - Composition: | (in weight %) |
|---|---|
| $SiO_2$ | 59.5 – 65.5 |
| $Al_2O_3$ | 13.0 – 18.0 |
| $K_2O$ | 10.0 – 14.0 |
| $Na_2O$ | 4.0 – 8.0 |
| Other Oxides | 0.0 – 3.5 |
| Pigments | 0.0 – 2.0 |

The composition of opaque is as follows: -

| Standard - Composition: | (in weight %) |
|---|---|
| $Al_2O_3$ | 9.5 – 17.0 |
| $SiO_2$ | 36.0 – 62.0 |
| ZrO2 | 15.0 – 39.0 |
| $K_2O$ | 7.5 – 14.0 |
| $Na_2O$ | 3.5 – 7.5 |
| Other Oxides | 0.0 – 3.5 |
| Pigments | 4.0 – 20.0 |
| Glycole | 26.0 |

The results of the study showed that IPS Classic had almost 3 times more tensile bond strength compared to the tensile strength of IPS Classic according to the manufacturer claims of 8MPa.This could owe to fact that DMLS created metal alloys have better bond strength between metal and ceramic [48].

For better understanding the bond strength between metal and porcelain, four mechanism have been described. They include: -

1. Mechanical entrapment

2. Compressive forces

3. Van der waals forces

4. Chemical bonding

Mechanical entrapment basically, creates an attachment by interlocking the ceramic into the micro-abrasions on the surface of the metal coping which are created by finishing the metal with non-contaminating stones / discs or abrasives.

Air abrasion appears to enhance the wettability, provide mechanical interlocking. The use of a bonding agent having platinum spheres of 3-6 μm diameter can also increase the bond significantly.

Compressive forces are developed by a properly designed coping and a slightly higher coefficient of thermal expansion than the porcelain veneered over it. This slight difference will cause the porcelain to draw towards the metal coping when the restoration cools after firing.

Vander waals forces create an affinity based on a mutual attraction of charged molecules. They contribute to only minor forces for bonding between metal to ceramic.

Chemical bonding is indicated by the formation of an oxide layer on the metal. Trace elements like tin, indium, gallium/iron in the metal, form oxides and bond to similar oxides in the opaque layer of the porcelain. [88],[90]

Among all the mechanisms determining the metal–ceramic interaction, chemical bonding is the predominant factor.[16] Chemical bonding is known to be influenced by the elemental composition of metal alloys and the formation of an oxide layer on the metal surface. The metal oxide layer has been studied extensively and shown to play an important role during metal–ceramic bonding. If the oxide layer is thin, it would be completely eliminated during ceramic firing. However, an excessively thick oxide layer may also weaken bonding strength since it has poor cohesive strength.(91) In the current study, a pre-oxidation step in the manufacture of metal alloys was omitted in accordance with the manufacturer's previous study and recommendations. Bond strength may also be improved by increasing the surface roughness of the alloy.

The results of this study showed that the blocks of Laser sintered Co-Cr which was not subjected to Laser welding or Spot welding had higher bond strength values as compared to the blocks of Laser sintered Co-Cr which had been Laser welded and Spot welded. The results of the study were in accordance with studies conducted by Aladag et al (3) which stated that soldering and laser welding results in a decrease in the physical and mechanical properties of Ni-Cr-Mo frameworks, and also in a decrease in the bond strength between the metal and ceramic.

Another study conducted by Galindo et al (18) related the bond strength between metal and porcelain, but did not find a significant difference between the specimens that were soldered and the specimens that were not soldered. This outcome maybe different due to difference in metal used or test parameters. Renata Marques et al, (29) in 2005 studied the difference in the shear bond strength between Ni-Cr and Co-Cr alloys to porcelain and concluded that no significant difference was noted in the bond strength between the two metal alloys to porcelain. This could be attributed to the difference in test parameters.

Nikellis et al (27) did a study comparing the strength of FPD frameworks once they were sectioned and welded. In his study he did not find any significant difference in the bond strength, which contradicted the results of the current study.

The difference in bond strength could be due to the fact that IPS Classic ceramic was used here. The Co-Cr alloy dictates better bond strength towards VITAVM® 13 and Wieland Reflex® since these newer age ceramics show extremely good homogenecity and bubble-free opaque and dentine layers according to manufacturer claims.

EOS CobaltChrome SP2 Co-Cr alloy powder also required that welding filler material BEGO Wiroweld wire of 0.35 mm diameter or 0.50 mm diameter to be used according to the manufacturer's instructions. In the study, DENTARUM Co-Cr Schweibraht welding wire was used instead. This could create a difference in welding and bond strength between metal and ceramic since BEGO Wiroweld is Carbon free and carbon reduces the strength of the welded metal.

Adaias et al [(78)] on the other hand, compared the flexural strength of Co-Cr and Ni-Cr to porcelain with and without TIG welding. He concluded that TIG welded specimens had better flexural strength than the specimens that weren't welded. This study concludes that welding could be a good option since it has been proved that welding is a viable option in dentistry. But TIG welding is superior to conventional welding procedures thus proving it as a source of increased strength.

There could be several reasons why there was a difference in the bond strength of ceramic to DMLS Co-Cr metal alloy. They are:-

1. For proper welding to happen, both ends of both metals should be hot enough for a proper welding to occur. Welding does not occur on an end which is cooler than the other.

2. Generally, a metal after welding should be annealed or cooled slowly. A rapid cooling of the metal could lead to formation of cracks, a phenomenon called as cracking (in metallurgy) and cause weak joints resulting in less strength at the welded joint.

3. Due to inefficiency of the operator, sometimes areas other than the welded joint maybe heated causing undesired stresses within the material thus weakening the internal structure of the metal and thus causing distortion.

4. Oxidation of metals can cause a defective joint during welding. However modern age technologies inherently prevent them by having a shield gas such as argon within the welding area.

5. Slag, that is dirt, debris and oxides can cause inefficient union within the welded joint and result in porosities and lack of a homogenous structure within the welded joint.

6. The parts to be welded have to be dry before welding if not, bubbles or porosities can result which can cause weaker joints. [(87), (88), (89), (90)]

In the study the cause for a weaker joint could be due to inadequate heating of both parts of the metal to be welded and presence of slag prior to welding. [(39),(91), (92)]

Mechanical failures of metal–ceramic systems are not surprising considering the vast differences in modulus between the metal and ceramic materials. The IPS Classic is a feldspathic ceramic and when feldspathic dental porcelain is cooled, the leucite crystals contract more than the surrounding glass matrix leading to the development of tangential compressive stresses around the leucite particles as well as to microcracks within and around the crystals. [(69),(73),(93)]

This could cause a weaker structure within the ceramic due to the propagation of cracks within the ceramic substructure.

Hence, within the limitations of the study it can be concluded that Laser welding and Spot welding result in a decrease in the µTBS between porcelain and Direct Metal Laser Sintered Co-Cr metal alloy. The difference though not by much, was statistically significant.

# CONCLUSIONS

The study can be concluded that:-

Direct Metal Laser Sintered Co-Cr metal alloy has clinically acceptable bonding towards porcelain. The results showed that Laser welding and Spot welding reduces the bond strength between porcelain and metal alloy, but still the bond strength ends up being in a clinically acceptable level dictating that there is adequate bond between porcelain and metal alloy to be used in a clinical scenario even though the metal has been welded. This signifies that welding does play an important role in the field of dentistry. DMLS has emerged as a very good alternative to conventional casting and according to various studies, has excellent accuracy, marginal adaptation and fit. Moreover DMLS cast metal alloys tend to leach fewer ions making them more biocompatible. Even though they are less performed in today's more developed times, misfits within long span FPDs can be corrected by sectioning and welding using a proper welding material and layered using ceramics to obtain a clinically acceptable and functionally durable fixed restoration.

To summarize, the study showed that DMLS Co-Cr metal alloys showed reduced bond strength to ceramic after laser welding and spot welding. Although the bond strength between ceramic and the metal alloy had reduced, the obtained values were within clinically acceptable ranges. Many limitations existed within the study, one being that, Scanning Electron Microscope (SEM) or Optical microscope studies were not performed to assess for mode of fracture such as adhesive or cohesive failures.

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# ANNEXURES

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# A101 & A102, KSSIDC Complex, Block II, Electronics City Phase I, Bangalore – 560100
Tel: 080-28528304, E mail: info@arml.in ; Website: www.arml.in

## TEST REPORT

| | | | |
|---|---|---|---|
| Order. No. /Report No. | : | 1905007-09 | Date : 17.05.2019 |
| Total Pages | : | Two | Page : 01 of 02 |
| **Customer** | : | Dr. Godwin George<br>St.Gregrios Dental College,Chelad, Kothamangalam<br>Kerala -686691 | |
| **Requested by** | : | Dr. Godwin George | |
| **Product Tested** | : | Dental Samples | |
| **Sample identification** | : | As below | |
| **Reference** | : | Email dated on. 29.04.2019 | |
| **Date of sample receipt** | : | 07.05.2019 | |
| **Sampling, if any** | : | N. A. | |

## Tensile Test

Test started on : 10.05.2017 Test completed on : 13.05.2019

Specification : N. A.

**Instrument Used :** Universal Testing Machine

**Rate of Speed :** 10mm/min

**Area : 22.99 mm$^2$**

| Order No | Sample Identification | Trial No | Ultimate Tensile Load, N | Tensile Strength, N/mm$^2$ |
|---|---|---|---|---|
| 1905007 | Laser welded | T-1 | 520 | 22.6 |
| | | T-2 | 550 | 23.9 |
| | | T-3 | 510 | 22.2 |
| | | T-4 | 510 | 22.2 |
| | | T-5 | 530 | 23.1 |
| | | T-6 | 520 | 22.6 |
| | | T-7 | 500 | 21.7 |
| | | T-8 | 550 | 23.9 |
| | | T-9 | 510 | 22.2 |
| | | T-10 | 520 | 22.6 |
| **Area : 23.52 mm2** | | | | |
| 1905008 | Spot welded | T-1 | 520 | 22.1 |
| | | T-2 | 540 | 22.9 |
| | | T-3 | 530 | 22.5 |
| | | T-4 | 520 | 22.1 |
| | | T-5 | 550 | 23.3 |
| | | T-6 | 540 | 22.9 |
| | | T-7 | 530 | 22.5 |
| | | T-8 | 570 | 24.2 |
| | | T-9 | 550 | 23.3 |
| | | T-10 | 530 | 22.5 |

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| | | | |
|---|---|---|---|
| Report/Order. No. | : 1905007-09 | Date | : 17.05.2019 |
| Total Pages | : Two | Page | : 02 of 02 |

**Area : 23.52 $mm^2$**

| Order No | Sample Identification | Trial No | Ultimate Tensile Load, N | Tensile Strength, $N/mm^2$ |
|---|---|---|---|---|
| 1905009 | Blocks without groove | T-1 | 560 | 24 |
| | | T-2 | 580 | 25 |
| | | T-3 | 560 | 24 |
| | | T-4 | 570 | 24 |
| | | T-5 | 580 | 25 |
| | | T-6 | 560 | 24 |
| | | T-7 | 580 | 25 |
| | | T-8 | 550 | 23 |
| | | T-9 | 580 | 25 |
| | | T-10 | 580 | 25 |

Authorized Signatory
(Ramesh.B)

------------------ End of the Report ------------------

**ST.GREGORIOS DENTAL COLLEGE**

UNDER THE MANAGEMENT OF MJSCE TRUST, PUTHENCRUZ

CHELAD , KOTHAMANGALAM, ERNAKULAM DIST, KERALA - 686681

## ETHICAL CLEARANCE CERTIFICATE

SGDC/152/2017/1733/6 Date:- 20-10-2017

To,

Dr.Godwin George Kurian
St. Gregorios Dental College
Chelad, Kothamangalam

Dear Dr. Godwin George Kurian,

Subject: - Ethics Committee Clearance Reg.

Protocol – Effect of spot welding and laser welding on the bond strength of ceramic to laser sintered Co-Cr metal alloy: An *in vitro* study

After the Institutional Ethics Committee (IEC) held on 20th of October, 2017, this study was examined and discussed. After the consideration, the committee had decided to approve and grant clearance for the aforementioned study.

The members who attende

# ACKNOWLEDGMENT

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***In the name of God, the most beneficent and the most merciful, I begin***

***All Praise to God who has blessed me with the better things in life.***

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Above all, I thank and praise **JESUS** for his blessings, constant presence and guidance for bringing me thus far.

Date;

Kothamangalam *Dr. Godwin George Kurian*

# LIST OF ABBREVIATIONS USED

| No. | Abbreviations | Descriptions |
|---|---|---|
| 1. | ANOVA | Analysis of Variance |
| 2. | CAD-CAM | Computer Aided Designing – Computer Aided Manufacturing |
| 3. | Co-Cr | Cobalt Chromium |
| 4. | DMLS | Direct Metal Laser Sintering |
| 5. | F - Value | Variance of the group means |
| 6. | FPD | Fixed Partial Denture |
| 7. | µTBS | Micro-tensile bond strength |
| 8. | MPa | Mega Pascal |
| 9. | Ni-Cr | Nickel-Chromium |
| 10. | P-value | Probability of obtaining a result |
| 11. | SPSS | Statistical package for the social sciences |
| 12. | SD | Standard Deviation |
| 13. | TIG | Tungsten inert Gas |