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RESEARCH ARTICLE

# FACTORS AFFECTING THE CORE VENEER BOND STRENGTH OF METAL CERAMIC RESTORATIONS: A REVIEW

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**ABSTRACT**

**Statement of Problem:** One of the most common causes of failure of any metal ceramic restoration is the delamination of the veneering ceramic. This may be attributed to failure at the junction of metal and ceramic. To evaluate factors affecting the core veneer bond strength of metal ceramic restorations through a review of previously published articles.

**Materials and methods:** A thorough search was made in Pubmed and Google Search and articles collected were reviewed with respect to various factors affecting the core veneer bond strength of metal ceramic restorations.

**Results:** Most of the studies done were in vitro. Of all the factors evaluated, surface treatments were found to have a significant effect on the bond strength.

**Conclusion:** Metal ceramic compatibility, types of metal alloys, types of ceramic, various pretreatment methods, etc affects the bond strength of metal ceramic restoration. The effect of each of these variables should be properly understood and applied in the given clinical situation for predictable results.



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## INTRODUCTION

Metal ceramic restorations have been used in dentistry for decades. They combine the strength of a metal substructure with aesthetics of the veneering ceramic. A considerable drawback of metal ceramic restoration is the chipping and delamination of the veneering ceramic which may be due to failure occurring in metal ceramic bond. For clinical success of metal-ceramic restorations, the development of an optimal bond between ceramic and metal substructure is essential (Fernandes neto, 2006). The longevity of the metal-ceramic restorations is based on the formation of a stable bond between the two materials. The bond is mainly due to oxidation of metal and interpenetration of ions between metal and ceramic. To understand the failure of metal ceramic bond, it is imperative to know the factors affecting the bond strength. Three basic types of mechanisms exist in metal ceramic bonding: mechanical interactions, chemical bond and van der waals' forces.

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Mechanical retention depends on the superficial roughness of base metal alloy whereas chemical bonding is mainly due to formation of adherent oxide layer on metal surface and is the main factor for adhesion. Physical adhesion is formed by van der waals forces. The factors that may affect the bond strength of metal ceramic resorations were compiled in the ensuing literature review.

## MATERIALS AND METHODS

Articles cited were obtained through the use of Pubmed and Google Scholar. A search was made from year 1995 to 2016. The majority of articles are in vitro studies. Articles selected were based on many variables 1) alloys used 2) ceramic used 3) various techniques advocated 4) surface treatments, etc. The following keywords were combined "metal ceramic"," bond strength", "soldering", "air abrasion", "surface treatments", "metal ceramic compatibility", "recasting". A total of 51 articles were included for discussion in the review out of 120 articles found by search after considering the inclusion and exclusion criteria. (Table 1)

## Inclusion and Exclusion criteria

| Inclusion criteria | Exclusion criteria |
|---|---|
| In vitro studies | Only abstracts |
| Studies evaluating only fabrication procedures | Review articles |
| Publication in peer reviewed journal | Studies simulating oral conditions |
| Written in English | |

## Studies comparing bond strength among different alloys

| | Purpose | Result |
|---|---|---|
| Mofida R. Khmaj *et al* - 2014 | Compared bond strength among four noble alloys by conventional layering and press on technique. | Highest bond strength observed in high gold alloy. |
| Ahmadzadeh a *et al* -2013 | Compared base metal alloys with one noble alloy in terms of bond strength. | Compared to noble metal alloy, base metal alloys have more bond strength to porcelain. (Ni-Cr-T3) |
| Jun-tae hong and Soo-yeon shin - 2014 | Evaluated bond strength of porcelain to milingable Pd-Ag alloy. | There is no difference between milingable Pd-Ag alloy and precious metal alloy. |
| Renato morales joias *et al* -2008 | Compared the bond strength of five different alloys (Co- Cr, Ips d.sign 20, Ips d.sign 30, Remanium 2000, Heranium p, and Wirobond C) with a common dental ceramic. | Significantly higher bond strength was found with Ips 20 and Ips 30 |
| Mariana Pretti *et al* -2004 | Compared bond strength of two different Co-Cr alloys (Wirobond C, Remanium 2000) with common dental ceramic (Vita Zahnfabrik). | No significant difference |
| Renata marques de melo -2005 | Evaluated the bond strength between Ips d sign 20 and four types of base metal alloys. | *No significant difference* |
| Luis gustavo oliveira de vasconcellos *et al* -2011 | Evaluated gold alloy and cobalt chromium alloys using feldspathic porcelain. | No significant difference |

## Studies showing effect of air particle abrasion

| | Purpose | Result |
|---|---|---|
| Tolga ku¨lu¨nk *et al* -2011 | Evaluated effect of different air abrasion particles on metal ceramic restoration using two types of alloys. (Ni-Cr, Co-Cr) | Alternative air abrasion particles (30-50µm synthetic diamond particles and 60-80 µm cubic boron nitride particles) are superior to 50 µm Al2o3 particles. |
| Bo-hua li *et al* -2014 | Assessed the influence of surface treatments on bonding of metal ceramic restoration. | Bond strength of a Pd–Ag alloy can be improved by using air-particle abrasion (250 µm sizes) and degassing before porcelain firing. |
| Luis gustavo oliveira de vasconcellos *et al* -2011 | Evaluated the effect of airborne particle abrasion on strength of ceramic fused to Co-Cr alloy or gold alloys. | Such treatment is beneficial since bond strength was more than the specimen which had tungsten bur treatment |

## Studies showing effect of oxidation heat treatment

| | Purpose | Result |
|---|---|---|
| Shraddha Rathi *et al* -2011 | Evaluated the influence of oxidation heat treatment on metal ceramic bonding. | No significant rise in bond strength. |
| Shahin Rezaee Rokni *et al* -2007 | Assessed thickness of oxide layer on Ni-Cr alloy and its ceramic adherence. | Degassing under vaccum with sandblasting improves adherence. |
| Vaidya Vidya N *et al* (2013) | Studied the effect of conventional and double degassing technique on ceramometal bond strength | Lower bond strength observed with double degassing technique. |

## Studies comparing different surface treatments

| | PURPOSE | RESULT |
|---|---|---|
| B Bagis and D Oztas -2008 | Compared the effect of different types of grinding on bond strength. | Metal grinding done by carbide bur in multiple direction yields in superior tensile bond strength compared to specimen grinded in one direction. |
| Mee-Kyoung Son H and an-Cheol Choeb -2011 | Evaluated bonding strength of metal coping to porcelain (with laser textured Ni-Cr and Ni-Cr-Ti alloys) | The values of bond strength obtained by laser texturing were similar to those of sandblasting technique. |
| Nadira A. Hatim *et al* -2013 | Evaluated the effect of surface treatments on Co –Cr alloys on bond strength of restoration. | Revealed that polishing and oxidation results in least shear bond strength compared to those with sandblasting ($AlO_2$, 125µ) and oxidation. |
| N. Nieva *et al* -2012 | Compared bond strength between Co-Cr and titanium alloys with different surface treatments. | Standard treatments improved adherence of Co-Cr alloys. However, anodization process is required for titanium alloys. |

## Studies comparing different types of ceramic

| | Purpose | Result |
|---|---|---|
| Marjorie c. Wood, dmd *et al* -2007 | Compared two types of porcelain (with and without opaque layer) and two casting alloys.(high noble and base metal) | Presence of opaque porcelain generally leads to increase in the bond strength of restoration. |
| Mofida r. Khmaj *et al* -2014 | Evaluated the fabricating techniques and its effect on bond strength. (layering method and hot pressing ) | Mean bond strength exceeded the minimum requirements. |
| Daniel m. Schweitzer *et al* -2005 | Compared low fusing pressable leucite-based glass ceramic fused to metal to a feldspathic porcelain fused to metal. | Bond strength of both types of ceramics was almost equal. |

## Classification of studies

## THE ALLOYS USED

### Types of alloys (Table 2)

The type of metal-ceramic alloy affects the adhesion between porcelain and alloy. Noble alloys have good mechanical properties, and excellent bonding to veneering ceramic. Among the noble metal alloys that were compared with both press on and conventional layering methods, high gold alloys had the highest bond strength whereas alloys containing silver had the least bond strength (Khmaj, 2014). Use of titanium alloy as a substructure in PFM restorations has been investigated since it has superior properties compared to other metal alloys. When precious gold alloy was compared with gold-titanium alloy, it was found that gold –titanium alloy provides sufficient bond strength. Also it was noticed that metal –titanium oxide bond was weaker when compared to metal-ceramic bond in such alloys (Olivieri, 2005). The high cost of noble alloys make base metal alloys a more favourable option. They also allow thinner infrastructure fabrication due to greater rigidity compared to noble alloys (Ahmadzadeh, 2013). Non-precious Ni-Cr alloys have been widely used and have significantly higher bond strength to porcelain compared with precious metal alloy containing 32% of gold but same as that of millingable Pd-Ag alloy (Hong, 2014). Ni-Cr alloys are often replaced with the more biocompatible Co-Cr alloys. When Co-Cr alloys with differing compositions were compared noticeable difference in bond strength was observed (Joias, 2008). However Mariana Pretti *et al* found no significant difference in the two types of Co-Cr alloys with a common ceramic material **(**Petti, 2004**).** In contrast, there are studies demonstrating that the type of alloy have no effect on the bond strength of restoration (Marques de Melo, 2005; Oliveira de Vasconcellos 2011). According to the review of studies, comparable bond strength of base metal alloy to noble metal alloy and its economical advantage makes base metal alloy a preferred option for fabrication of metal ceramic restorations.

## Surface treatments

### Effect of air particle abrasion (Table 3)

When metal surface is treated with airborne particle abrasion, the surface area available for bonding increases. The wettability of metal surface by the ceramic is improved and hence there occurs a rise in metal ceramic bond strength due to micromechanical bonding. Also, contaminants on metal surface are removed (Papadopoulos, 1999) Aluminium oxide particles are most commonly used for this procedure. Other air abrasion particles to be used are diamond particles and boron nitride at an air pressure of 315 Pa for 15 seconds. Highest bond strength is obtained with 110µm Al2O3 (Ku¨lu¨nk, 2011). When air particle abrasion with Al2O3 was studied in different conditions,it was observed that bond is strongest with 250 µm Al2O3 and was weakest when the metal surface was etched and sandblasted (Gadge, 2015). Hence the data of the above studies indicates that $Al_2O_3$ air particle abrasion of the bonding surfaces have a significant influence on improvement of bonding mechanism of metal ceramic restorations.

### Effect of Oxidation heat treatments (OHT) (Table 4)

Oxide layer is of utmost importance for bond formation between porcelain and metal layer. It is formed during oxidation of the metal surface (Bo-hua Li, 2014). Various oxidation heat treatments are undertaken prior to ceramic application (Degassing, Outgasing and Preoxidation). This is done to remove the surface contaminants, entrapped gases and to form oxide layer (Annusavice, 1996). OHT increases the amount of oxides on base metal alloy surface, however there occurs no significant increase in bond strength with this process (Rathi, 2011). Shahin Rezaee Rokni *et al* assessed degassing treatment under different conditions (air and vaccum, followed by sandblasting) on Ni-Cr alloys and found that oxidation under vaccum with sandblasting improves the bond strength. This can be attributed to the ability to control the oxide layer on metal (Roknia, 2017). Double degassing is sometimes advocated with the idea that conventional degassing removes surface contamination and gas inclusion whereas second degassing provides oxide layer. However, in a study by Vaidya Vidya N *et al* bond strength with double degassing was found to be lower. This is due to the fact that the bonding layer is not created once the original oxide layer is removed (Vaidya Vidya, 2013).

### Comparing different surface treatments (Table 5)

Texture of metal has a significant influence on metal to ceramic bond. To improve the bond strength between the metal and ceramic, various surface treatments are used, such as oxidation of the metal prior to porcelain application, application of bonding agents, and airborne particle abrasion. However, standard pretreatment method of the metal surface before applying the ceramic is not confirmed (Vaidya Vidya, 2013). B Bagis and D Oztas recommends grinding of metal surface in multiple direction using light hand pressure to improve the retention for bonding (Bagis,, 2008). Laser surface texturing (LST) is a surface treatment method which makes easier control of micro-topography and improves the texture of metal favoring greater bond with ceramic (Deepak, 2013). Mee-Kyoung Son H and an-Cheol Choeb in their study used Femtosecond(FS) lasers which produces micropores or holes several micrometers deep with high precision and without spatter around the micropores.(about 20 µ) (Sona, 2011). Polished surface has higher bond strength compared to oxidized surface because of absence of gases which forms oxide layer and further porosities in metal porcelain interface. But the bond strength by above techniques was less compared to sandblasting and oxidation process (Hatim, 2013). Anodizing process on titanium surface leads to considerable increase in bond strength than the other surface treatments (oxidization, sandblasting) when compared with Co-Cr alloys. This is due to the generation of oxide layer of controlled thickness on the titanium alloy (Nieva, 2012). Since the metal oxide layer composition and amount is influenced by different surface treatments, it has a major role in improving the bonding mechanism in metal ceramic restorations. Treatment ranges from simple grinding of metal surfaces to techniques like anodizing and laser texturing. However, the standard pretreatment measures for the same are lacking.

## CERAMIC

### Types of ceramic (Table 6)

Three main types of porcelains are used in fabrication process of metal ceramic restoration: Opaque, Body and Incisal porcelain. Presence of higher amount of metal oxides in opaque porcelain makes the restoration esthetic by masking the metal substructure. The debonding / crack initiation strength is

### Studies showing effect of laser sintering

| | Purpose | Result |
|---|---|---|
| Tolga Akova *et al* (2008) | Compared bond strength of laser sintered and cast base metal alloys (Co-Cr and Ni-Cr alloys) | No statistically significant difference between the two groups. |
| Lin wu *et al* 2014 | Compared and studied the mechanical properties of laser sintered Co-Cr alloy with cast Co-Cr alloys | Improved mechanical properties and bond strength with laser sintering technique. |
| Eun-jeong bae *et al* (2014) | Compared the conventional casting and selective laser sintering in terms of bond strength. | Improved bond strength by selective lasers sintering. |
| Eun-Jeong Bae *et al* (2015) | Evaluated bond strength between lasers sintered metal structure and different ceramic system. | No significant difference between different ceramic materials. |
| Yihan Liu *et al* (2009) | Evaluated mechanical properties and porcelain bond strength of laser rapid formed nickel chromium alloy. | Improved mechanical properties and bond strength. |

### Studies showing effect of recasting

| | Purpose | Result |
|---|---|---|
| Dr. Priyanka Mahale *et al* (2014) | Evaluated the bond strength of nickel chromium alloys with various percentages of recast alloys. | Upto 50 percent of recast alloy does not have significant effect on bond strength. |
| Kaleswara Rao Atluri *et al*(2014) | Compared the metal ceramic bond strength of Ni-Cr and Co-Cr alloys on repeated casting. | Significant reduction in bond strength on repeated casting. |
| Esra Kul *et al* (2015) | Compared metal ceramic bond strength of noble and base metal alloys after recasting. | No effect on porcelain compatibility after recasting on noble alloys compared to base metal alloy. |

### Studies comparing effect of soldering and welding

| | Purpose | Result |
|---|---|---|
| Daniel f. Galindo *et al* (2001) | Assessed effect of solder material on bond strength of metal ceramic restoration in Pd-Ga alloys. | Solder material does not decrease the overall metal porcelain bond strength. |
| Ioannis nikellis *et al* 2005 | Assessed effect of solder material in nickel based alloys on bond strength. | Addition of solder base alloy had no effect on bond strength. |
| Akin aladag *et al* (2010) | Evaluated the effect of soldering and laser welding on bond strength of metal ceramic restoration (Ni-Cr alloys) | Soldering and laser welding significantly decreases the µtbs of a veneering ceramic to a base metal alloy. |
| Husain a. Ghadhanfari( 2014) | Compared the tensile strength of microwave post ceramic soldering,<br>Conventional post ceramic soldering and laser post ceramic welding. | Microwave soldering results in higher tensile strength than conventional soldering and laser welding of a gold-palladium metal ceramic alloy |

### Studies showing effect of porcelain firing atmospheres

| | Purpose | Result |
|---|---|---|
| Abdulaziz Sadeq *et al* (2003) | Assessed different porcelain firing atmosphere along with interfacial variables. | Marked increase in bond strength in reduced argon atmosphere. |
| Saadet Atsü *et al* ( 2000) | Assessed the two firing atmosphere conditions on titanium porcelain bonding | Conventional porcelain to Ni-Cr bond strength was superior than titanium porcelain strength in different firing conditions. |

### Studies showing effect of interfacial materials

| | PURPOSE | RESULT |
|---|---|---|
| Shaymaa E. Elsaka *et al* (2009) | Evaluated effect of chromium interlayer on titanium porcelain bond. | In case of titanium alloys, the bond strength can be improved by use of chromium interlayer prior to porcelain firing. |
| Trindade *et al* (2014) | Evaluated the effect of bonding agent on ceramic to gold and cobalt chromium alloys. | Improved the bond strength of gold alloys, but did not affect co- cr alloy. |
| Lan Yao *et al* (2013) | Studied the effect of adding Tio2 and MoO3 added to porcelain. (leucite reinforced) | wettability of ceramic improved but there was no effect on bond strength. |
| N. Suansuwan *et al* (2003) | Evaluated the adhesion to porcelain of titanium alloy with different bonding agents. | Goldbonder enhanced adhesion of porcelain to titanium |
| Masaki Asakura *et al* (2012) | Asessd levels of zinc in gold based alloys on porcelain metal bonding. | Presence of zinc at the interface leads to improvement in bonding strength. |
| Abdulaziz Sadeq *et al* ( 2003) | Assessed the effect of interfacial variables on cast and machined pure titanium | Intermediate Gold coating on titanium surface improves bonding in reduced argon atmosphere. |

### Studies showing metal ceramic compatibility

| | Purpose | Result |
|---|---|---|
| Alferdo julio fernandes neto *et al* (2006) | Compared bond strengths of three different ceramic systems using three Ni-Cr and one experimental Co-Cr- Ti alloys. | Bond strength varied significantly with the three ceramic systems. (Vita vmk88, Williams, Duceram) and with three nickel chromium alloys. |
| Stella crosara lopes *et al* (*2009)* | Evaluated the bond strength in terms of coefficient of thermal expansion of metal and ceramic. | There was no correlation of evaluated metal ceramic pairs. (2 Ni-Cr alloys and 1 Pd-Ag alloy with 2 Dental Ceramics) |
| Renata marques de melo *et al* (2005) | Compared the shear bond strength between a porcelain system (Ips d. Sign system) and 4 alternative alloys including ips d. Sign 20 alloy. | Any of the alloys tested can be used with ips d.sign since there was no significant difference between alloys tested. (Co-Cr, Ni-Cr). |

improved by the use of opaque layer. However its magnitude depends on type of metal ceramic combination, base metals having favorable result due to presence of more concentration of oxidizable elements (Wood M., Thompson.m 2007). When two opaquing techniques were evaluated (single masking layer and double masking layer), no significant difference was found in bond strength of base metal and noble metal alloys. However, application of opaque porcelain over oxidized surface of alloys significantly improved the bond strength in noble metal alloys (Rake P, 1995). For many decades, dental laboratories used layering methods which involved sintering of several dental porcelain layers over metal coping. An alternative method has been investigated which includes rapidly hot pressing ceramic onto the copings. There are various limitations to the use of hot pressing of ceramic for e.g. They cannot be used onto the alloys containing more than 10 % Ag, if thermal coefficient of contraction is not matched with the alloy, if specimen is very thin, etc. when bond strength was compared among the techniques; high noble alloys with conventional technique were found to have superior strength to the press on metal technique. However the mean bond strength of each specimen exceeded the minimum requirement (Khmaj, 2014).

**Techniques**

**Effect of Laser sintering: (Table 7)**

Laser sintering is a promising new technology which replaces casting of base metal alloys. It involves melting and laminating a metal powder with a laser on the basis of modeled CAD data without fabricating dies. The porcelain to laser sintered Co-Cr alloy when compared to cast Ni-Cr and Co-Cr alloys revealed no significant difference in bond strength. However, the type of failure observed mostly in laser sintered specimens was adhesive, indicating the intimate bond of porcelain to metal (Sadeq 2003). When laser sintered Co- Cr alloy was studied in detail regarding the mechanical properties, Energy dispersive x-ray spectroscopy and Electron probe microanalyzer analysis revealed elemental interpenetration at the bonding interface of the selective laser melting alloy (cobalt chromium alloy fabricated with the EOSINT M270 system) and porcelain which improved the bond strength/ (Nikellis, 2005). The higher bond strength in laser sintering was also attributed to the gaps which are caused by manufacturing method which increased the surface area which enhanced the penetration of ceramic powder into the gaps. According to Gu and Shen, it was mainly due to the balling phenomenon which occurs during layer by layer lamination by laser sintering. The balls formed at this time on the surface increases the surface area by forming undercuts (Akovaa T., Ucara, 2008). When different ceramic powders were used on laser sintered Co-Cr alloy and mechanical properties were studied, no significant difference were found between the materials. Hence it was concluded that a variety of powders can be used on laser sintered metal structure (Liu, 2009). Higher porcelain bond strength in laser rapid formed Ni-Cr alloy was attributed to the formation of finer columnar dendrites due to rapid solidification. Also, compositional segregation and metallurgical defects are avoided which leads to improved strength (Liu, 2009). Due to its favorable result in terms of bonding of metal to ceramic, laser sintering is a better fabrication option for metal ceramic restoration.

**Recasting (Table 8)**

In the dental laboratory, reuse of previously casted alloys by combining it with new alloy has been a common practice. Authors recommend adding upto 50 percent of new alloys to surplus alloy from previous casting. Due to the potential loss of certain trace base metals, (Zn, In,Sn, and Fe) the bond strength of metal ceramic restorations gets adversely affected (Walczak, 2014 and Madani, 2011). More than 50 percent of fresh alloy yields in superior bond strength in case of Ni-Cr alloys. However, in this study only once recast alloys were used (Mahale, 2014). Kaleswara Rao Atluri *et al* proved that addition of recast alloy to fresh alloy significantly decreases the bond strength of metal and ceramic. This may be attributed to increase interfacial voids as the percentage of recast alloy is increased. Also due to the compositional change that occurs after multiple casting (Atluri, 2014). When base metal alloys were compared to noble metal alloy in terms of recasting, it was seen that noble metal alloys can be remelted and there was no problem with porcelain compatibility whereas bonding capabilities for base metal alloys are lowered after second and third casting (Kul, 2015). According to the studies reviewed, it is possible to have production of durable casting, nevertheless, use of 50 % new alloy is recommended and the recast alloy is not used more than twice. However, process of recasting leads to the alteration in composition of metal oxide surface layer which may be of critical importance for bonding of metal to ceramic.

**Effect of soldering and welding: (Table9)**

Soldering is routinely used to add proximal contacts or repair casting defects. Even if the soldered area is small, problem like delamination of ceramic occurs due to crack propagation initiating from this area. Addition of solder material should not affect the quality and longevity of metal ceramic restorations. Studies demonstrate that there is no effect on bond strength when soldering was done in Pd –Ga alloys (Galindo, 2001) and Ni-Cr alloys. However the mechanical properties were found to be inferior to the non soldered specimens. (Vaidya Vidya, 2013) Laser welding technique has been used in conjunction to soldering technique wherein laser is used to heat the metal parts especially when similar metal parts are to be joined. Decrease in bond strength may be attributed to alteration of grain size of parent alloy due to heat and melted filler metal occupying a large area, thereby decreasing the tensile strength. Also, soldered part had less stiffness compared to the non soldered parts leading to plastic deformation under lower loads. This results in ceramic fracture since ceramic cannot compensate the plastic deformation. (Aladag A., Çömlekoglu, 2010). Microwave heating for soldering has various advantages including energy saving, reduction in heating cycle time, rapid heating, etc. Higher metal ceramic bond strength found in microwave soldering is due to microwave volumetric heating process and also due to lack of areas of complete sintering observed in the conventional soldering process Ghadhanfari, 2000). Both pre ceramic and post ceramic soldering considerably lowers the bond strength between metal and ceramic due to a number of reasons like alteration in chemical composition at soldered area, formation of gas inclusion and excessive oxidation by uncontrolled temperature of gas flame, flux inclusion at the site due to higher concentration of flux. So also, laser welding significantly decreases the bond strength due to alteration in physical and mechanical properties of materials. Hence, remaking of a defective restoration might be a preferred option compared to soldering and welding.

**Porcelain Firing Atmospheres: (Table10)**

When different porcelain firing atmospheres were compared for titanium alloys, it was seen that the adherence of titanium to porcelain was improved in reduced argon atmosphere. This improvement is attributed to the fact that argon limits formation of nonadherent oxide on titanium surfaces thereby increasing the bond (Sadeq, 2003). Study by Saadet Atsü *et al* has also proved that porcelain firing done under reduced argon atmosphere for conventional porcelain to Ni-Cr alloy had higher bond strength when compared to various titanium-porcelain systems. (Atsü, 2008).Hence, to conclude, reduced argon atmosphere, due to its inherent property of reducing oxidation effect of porcelain firing atmosphere tends to improve the metal ceramic bond strength in comparison to the conventional vaccum firing for base metal alloys as well as titanium alloys.

**Effect of interfacial materials (*Bonding agents*) (Table 11)**

A bonding agent is a component of PFM system which is present between the metal core and outer aesthetic layer. It provides good bonding between the two components by forming the oxides required for adhesion between the alloy and ceramic.

**Functionally graded metal ceramic restorations**

to have a graded transition between the metal substructure and ceramic veneer, metal ceramic composite interlayer is introduced at the interface followed by heat pressing technique.

Use of chromium as an interlayer, helps in improving adhesion between porcelain and titanium by forming a dense Chromium oxide layer and acts as oxygen diffusion barrier (Elsaka, 2009; Elsaka, 2009). A study by Trinadade *et al* demonstrated that flexural bond strength was improved by use of a bonding agent (wash opaque) for gold alloys whereas it was not significant in case of Co-Cr alloy. A wash opaque layer forms the oxide required for adhesion of metal and porcelain. (Trindade, 2014). N. Suansuwan *et al* in their fracture toughness study have proven that titanium alloys when used with “Goldbonder” bonding agent show superior bond strength than Ni-Cr alloys. They also proved that the paste bonders used with the alloys are not sufficiently tough to resist the crack propagation and hence cracks usually starts in the bonder layer. Presence of gold particles in “Goldbonder bonding agents” helps in adhesion of porcelain by inhibiting excessive oxidation on titanium surface (Suansuwana, 2003). Due to presence of high concentration of zinc at porcelain alloy interface in gold alloys, it was assumed that zinc has an effect on porcelain metal bond strength. In a study conducted to assess the effect of zinc level in gold based alloys on bond strength, it was observed that when alloy was preoxidized , zinc was highly localized on the interface and diffused in porcelain by around 10µ which leads to improvement in bond strength (Asakura, 2012).

Use of intermediate gold layer on titanium surface leads to marked increase in titanium ceramic bond strength in case of machined titanium specimen provided the porcelain firing is done under reduced argon atmosphere. Gold coating prevents formation of non adherent oxide on titanium surface by preventing inward diffusion of oxygen onto titanium and outward diffusion of titanium towards the surface (Sadeq A.,, 2003). Unlike conventional metal ceramic restorations, the presence of interlayer between metal and ceramic (functionally graded restoration) will avoid sharp transitions between the materials and improves the bond strength by reducing the interface stresses. The interlayer present could be any of the following: metal matrix composite, chromium interlayer, gold coating or silicon coating applied by magnetron sputtering. However, studies to compare and give an ideal interlayer material of choice are lacking.

**Metal –ceramic compatibility (Table 12)**

Restoration can withstand the mechanical forces and thermal stresses only if there is optimal bond between base metal alloy and ceramic, which depends on good chemical compatibility between the two materials. Alfredo julio *et al* in their study demonstrated significant differences in bond strength between various combinations of metal and ceramic emphasizing the importance of metal ceramic compatibility (Fernandes neto, 2006). Higher bond strength in experimental group (Co-Cr- Ti alloy) in this study may be attributed to the presence of titanium. Metal and porcelain should have similar coefficient of thermal contraction, metal having slightly higher value to avoid undesirable tensile loading at interface (Anusavice, 2003). Few studies have inferred that there is no such correlation between coefficient of thermal expansion and bond strength (Schweitzer, 2005). However, this study did not follow the manufactures recommendation i.e. there was no preheating treatment performed. Different porcelain manufacturers recommend their own metal systems as the most compatible for fabricating metal-ceramic prostheses e.g. ips d. Sign20 alloy which was specially developed for ips d. Sign system but when evaluated with different base metal alloys had no significant difference in the strength. To conclude, according to various studies, success of metal ceramic restoration depends upon the compatibility of the two materials selected such that they should not undergo fatigue or fracture under different clinical conditions. It is also important to take into consideration that due to advent of newer materials, constant research is required to assess this compatibility.

**Summary**

The included studies are summarized in tables 2 to 12. Each factor influences the bond strength to a certain extent. Even though noble alloys have good results compared to base metal alloys, the latter has predictable result. Base metal alloys are routinely used since they are economical and are characterized with thin infrastructure. Laser sintering has replaced casting techniques for the fabrication of base metal alloy copings to improve bond between porcelain and metal. Recasting significantly decreases the bond strength. However, it is noted that the recast alloy should have the presence of more than 50 percent of new alloy and it is more preferred in noble metal alloys. While considering surface treatment for bond strength, the standard has not yet been confirmed. However, laser surface texturing and anodizing process for titanium provides good result. Nonetheless, various studies suggested that air particle abrasion (110 µm $Al_2O_3$) and oxidation heat treatment improves the bond strength. Bonding agents incorporated with gold and zinc particles have proven to increase bond strength in titanium and noble metal alloys. Also, interlayers such as metal ceramic composite and chromium have been incorporated in metal ceramic and titanium restorations respectively to improve the bond strength. Application of opaquer results in increase in bond strength in noble metal alloys, however, a comparative evaluation of different opaquing techniques revealed no significant difference. Reduced argon in porcelain firing atmospheres contributes to increase bond strength since argon limits formation of non adherent oxides on coping surfaces. To alleviate the disadvantages of conventional soldering technique used to repair metal ceramic restoration, microwave soldering has been advocated. Compatibility between metal and ceramic is dependent on manufacturers' specifications.

**Conclusion**

This review of literature includes in vitro studies done on different factors influencing bond strength in metal ceramic restorations. Based on the review, it can be concluded that Improvements have been noted following advances in material properties of alloys and ceramics, surface treatment and fabrication techniques. It is important to understand that the success of metal ceramic restorations depends upon the understanding of material properties and compatibility of these materials. Of all the factors evaluated, certain factors like use of base metal alloys, laser sintering procedure and fabrication of functionally graded restoration using interlayer material proves to be promising options for improving the strength. To improve the longevity of restorations, the procedures like recasting, soldering and welding should be best avoided. Surface treatment has a significant role for the improvement of bond strength but the best pretreatment method to be used cannot be concluded.

**Conflict of Interest:** Nil

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