Research, Society and Development, v. 11, n. 7, e2711729626, 2022
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v11i7.29626

Flexural strength of milled polymer bars, with and without glass fiber reinforcement

Resistência a flexão em barras poliméricas fresadas, com e sem reforço de fibras de vidro

Resistencia a la flexión en barras de polímero molidas, con y sin refuerzo de fibra de vidrio

Received: 04/26/2022 | Reviewed: 05/06/2022 | Accept: 05/08/2022 | Published: 05/14/2022

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Abstract
The aim of this study is to test and compare the flexural strength of milled polymer bars, with and without glass fiber reinforcement. The number of samples in the study was defined through a pilot study on a universal testing machine (EMIC) (n = 5). The brands analyzed in this study were Arch Free Metal, Zantex, Bioplas and PEEK. All samples were submitted to thermal aging before the three-point flexural test. Fracture patterns were analyzed using a Scanning Electron Microscope. Results show that the Arch Free Metal bar presented the largest flexural strength, followed by Zantex and PEEK bars, that lacked statistical difference, and Bioplas bars. Regarding fracture patterns, Arch Free Metal and Zantex bars were partially fractured and showed partial glass fiber rupture; PEEK bars were not fractured and showed plastic behavior; and Bioplas bars were fractured. It is possible to conclude that the reinforced polymer bar Arch Free Metal has a better performance in terms of flexural strength than the other tested materials.
Keywords: Dental materials; Flexural strength; Biomaterials.

Resumo
O objetivo desta pesquisa foi testar e comparar a resistência a flexão de barras poliméricas fresadas, reforçadas ou não com fibras de vidro. Para estabelecer o número amostral realizou-se um estudo piloto na máquina de ensaios universais (EMIC), definindo n=5. As marcas testadas foram os polímeros Arch Free Metal, Zantex, Bioplas e PEEK**.** Todas as amostras foram submetidas a um envelhecimento térmico prévio e ao teste de flexão a três pontos. Foram analisados os padrões de fratura no microscópio eletrônico de varredura. Os resultados mostraram que a barra em Arch Free Metal

obteve valores de resistência a flexão significativamente superiores aos encontrados nas barras de Zantex e PEEK, que obtiveram resultados semelhantes entre si e estas, por sua vez, mostraram resistência estatisticamente maior que a barra confeccionada em Bioplas. Quanto aos padrões de fratura, as barras de Arch Free metal e de Zantex apresentaram fratura e rompimento parcial das fibras de vidro, enquanto as de PEEK não chegaram à fratura e demostraram um comportamento plástico, já as de Bioplas fraturaram. Conclui-se que a barra polimérica reforçada de Arch Free Metal pode apresentar melhor desempenho que barras confeccionadas com os demais materiais no que diz respeito à resistência à flexão.
Palavras-chave: Materiais dentários; Resistência à flexão; Biomateriais.

Resumen
El objetivo de esta investigación fue probar y comparar la resistencia a la flexión de barras de polímero molidas, reforzadas o no con fibras de vidrio. Para establecer el número de muestra se realizó un estudio piloto en la máquina universal de ensayos (EMIC), definiendo n=5. Las marcas probadas fueron Arch Free Metal, Zantex, Bioplas y PEEK Polymers. Todas las muestras fueron sometidas a un envejecimiento térmico previo y al ensayo de flexión en tres puntos. Los patrones de fractura se analizaron en el microscopio electrónico de barrido. Los resultados mostraron que la barra Arch Free Metal obtuvo valores de resistencia a la flexión significativamente superiores a los encontrados en las barras Zantex y PEEK, las cuales obtuvieron resultados similares entre sí y estas a su vez mostraron resistencia estadísticamente mayor que la barra fabricada en Bioplas. En cuanto a los patrones de fractura, las barras metálicas Arch Free y Zantex presentaron fractura y ruptura parcial de las fibras de vidrio, mientras que las barras de PEEK no alcanzaron la fractura y mostraron un comportamiento plástico, mientras que las de Bioplas se fracturaron. Se concluye que la barra polimérica reforzada Arch Free Metal puede tener un mejor desempeño que las barras fabricadas con otros materiales en cuanto a resistencia a la flexión.
Palabras clave: Materiales dentales; Fuerza flexible; Biomateriales.

1. Introduction

Dentistry is witnessing an increase in the number of patients demanding metal-free rehabilitation treatments (Schwitalla et al., 2013). Current technology enables the use of effective metal-free materials with favorable properties for rehabilitations (Carvalho et al., 2017; Grecco et al, 2022).

Polymer-based structures, with or without glass fiber reinforcement, have been suggested as alternatives to metal in rehabilitations over implants (Ávila et al., 2019; Carvalho et al., 2017; Martino et al., 2019); however, their recommendation still depends on more studies.

Polyether ether ketone (PEEK) is a high-performance semi-crystalline polymer with good mechanical properties (Anzolin et al., 2019), is stable in the oral environment, presents good aesthetical results and is an alternative to patients with metal allergies (Aquino et al., 2018; Jaros et al.,2019). Arch Free Metal consists of an epoxy resin matrix reinforced with multidirectional glass fibers (Yilmaz et al.,2019) with excellent results in implants (Gumbau et al., 2019). Zantex is a recently developed glass fiber-reinforced compound (Bergamo et al., 2021), that lacks studies on its flexural strength. Bioplas is a metal-free polymer with elasticity module similar to the bone’s, used in Dentistry, but lacking studies to support its use.

In this context, the present study aims to analyze the flexural strength of milled polymer bars, with and without glass fiber reinforcement. Materials analyzed are: Arch Free Metal, Zantex, Bioplas, and LuxaCam Peek.

2. Methods

This study was approved by the Research Ethics Committee (#2020-0573) of the Dentistry School of São Leopoldo Mandic University – Campinas, SP.

First, a pilot study was conducted with 5 samples per group. Based on the digital design, the bars were milled on a mini-milling machine Zenotec (Wieland Dental, Stuttgart, Germany). The milling machine used was DMX-50-5- axil dental mill-roland DGA Corporation. Computer-aided design of the blocks was run on Exocad (Exocad America.Inc, 2010).

Four groups of milled bars were defined:

Group G1 – Zantex (Biofunctional Materials, Boca Raton, Florida, USA).

Group G2 – Bioplas (Zarethe Ceramic LTDA, São Carlos, São Paulo, Brazil).

Group G3 – Arch free metal (Defama, Porto Alegre, Rio Grande do Sul, Brazil).

Group G4 – LuxaCam Peek (DMG Chemisch -Pharmazeutische Fabrik GmbH, Hamburg, Germany).

The bars were manufactured as solid pieces, with rectangular cross-section measuring 6mm x 4mm x 20mm (Carvalho et al., 2017).

Samples were aged with 9900 cycles of thermal cycling with water baths between 5◦C and 55◦C, with dwelling time of 30 seconds in a thermal cycling device.

Specimens were submitted to a three-point flexural test – two support points below the specimen and one moving point that applies pressure to the upper surface of the specimen until fracture/deformation. Distance between the support points was defined as 9 mm (Carvalho et al., 2017).

The flexural test was conducted on a EMIC DL2000 (EMIC, São Paulo, Brazil) (Figure 1), using a load cell of 200N and actuator speed of 0.5 mm / min.

Figure 1 - Test on EMIC DL2000.

Source: own authorship.

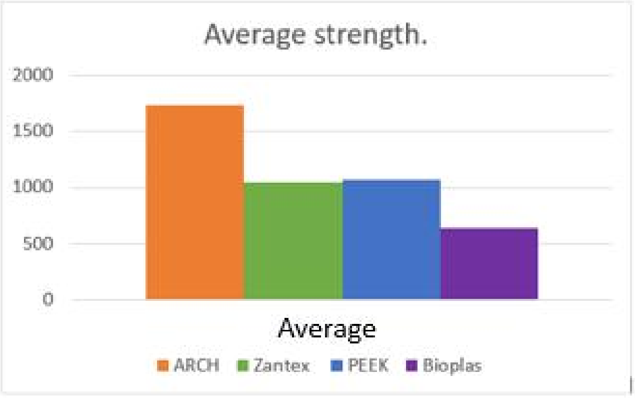
Levene's test was applied to verify normality and one-way ANOVA and Tukey's test were used for comparisons.

One polymer specimen for each brand was assessed for fracture patterns on a Scanning Electron Microscope (SEM), as described in Yasue et al. (2019).

3. Results

One-way variance analysis showed that the type of material influences the sample's flexural strength ($p > 0.01$). Our results show that the Arch Free Metal (DEFAMA) bars present the largest flexural strength among the materials tested, followed by Zantex and PEEK bars, that are followed by Bioplas bars (Table 1 and Graph 1). More specifically, Arch Free Metal bars were 38.6% more resistant to fracture than Zantex and PEEK bar, and 62.96% more resistant than Bioplas bars. Zantex and PEEK bars showed no statistical difference in terms of flexural strength and were 39.67% more resistant to fracture than Bioplas bars.

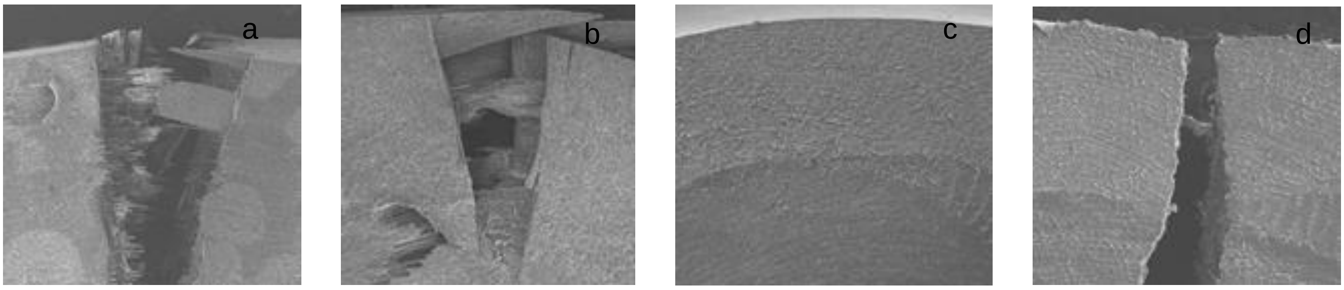
Graph 1 – Average flexural strength (Fracture) in N according to material type.



Source: Own authorship.

Scanning Electron Microscopy showed differences in terms of fracture patterns between materials. (Figure 2)

Figure 2 - Scanning electron microscopy images of the different materials analyzed.



Caption: a) Arch Free metal b) Zantex c) PEEK d) Bioplas. Source: own authorship.

Bars manufactured in Arch Free metal (Figure 2.a) and Zantex (Figure 2.b) show partial fracture and partial rupture of glass fibers, while PEEK bars did not show signs of fracture and show plastic behavior (Figure 2.c). Bioplas bars were fractured when submitted to the flexural test (Figure 2.d).

4. Discussion

Polymer materials, whether reinforced or not, are potential alternatives to metal in Dentistry due to their favorable properties, making them interesting subjects for scientific research (Silva Júnior et al, 2018; Ávila et al., 2019; Peçanha, et al., 2021; Franco et al., 2022). The present study compared the flexural strength of different polymers and found that Arch Free Metal presented the largest resistance, followed by PEEK and Zantex, and Bioplas, that showed the worst performance.

In the present study, the material composition influenced the flexural strength, as opposed to the findings in Guzmán et al. (2008) that compared glass fiber reinforced and non-reinforced provisionals. Here, Arch Free Metal bars were 38.6% and 62.96% more resistant than PEEK and Bioplas bars, respectively. On the other hand, other studies corroborate our findings that reinforced materials can be more resistant than non-reinforced materials (Bae et al., 2001; Ávila et al., 2019). A more rigid structure is biomechanically advantageous and allow the production of thinner and more resistant prostheses. In addition to that, it allows a better distribution of loads, thus reducing stress on implants, prostheses and bone (Fajardo et al., 2011; Menini et al., 2015). In the present study, the non-reinforced polymer samples represented by Bioplas was less resistant than the other materials tested.

The present study agrees with Yilmaz et al. (2019), where Arch Free Metal was more resistant than PEEK when submitted to the flexural test and in the absence of a Titanium base; however, when used on a Titanium base, the statistical difference disappears. This was not considered in the present study.

Regarding the fracture pattern, PEEK bars showed no signs of fracture, but bended, showing PEEK's chemical and physical properties and high flexural strength. PEEK's flexural strength was comparable that of Zantex, a material reinforced with glass fibers. Arch free Metal and Zantex bars were partially fractured, since they contain reinforcement fibers; however their fracture patterns differed. Yasue et al. (2019) also found that compound resin and epoxy resin reinforced only with parallel fibers vertically disposed were fractured, while epoxy resin samples reinforced with parallel fibers vertically and horizontally disposed showed larger resistance. Therefore, Arch Free Metal and Zantex bars showed different patterns of flexural strength and fracture, despite their being both reinforced, mainly due to the orientation of their fibers. Maximum strength values for Zantex and Arch Free Metal were 1324.44N and 1907.15N, respectively.

A clinical report of a two-year follow-up of fixed protocol prosthesis over implants with Arch Free Metal reinforced with glass fibers showed good aesthetical results and functionality (Gumbau et al., 2019).

Under the same perspective, another study concluded that resistance is improved with glass fiber reinforcement to the point that it can overcome the mechanical restrictions of polymer-based prostheses, improving their flexural and fatigue properties. The authors also show that the fibers' elasticity module is high and postulate that the fibers are able to absorb stress without deforming (Tacir et al., 2006). This also corroborates our findings that Arch Free Metal bars are more resistant, the plastic behavior of PEEK bars, and the complete fracture of Bioplas bars on the mechanical test.

5. Conclusion

Arch Free Metal reinforced polymer bars present better performance to the flexural strength test, followed by Zantex and PEEK bars, with equal performance, and Bioplas, with poorer performance.

At the moment that this study was performed, the authors were not able to find any studies comparing the same four types of materials. Also, the authors were able to find studies comparing PEEK to materials with and without reinforcement, but the samples names were not specified. No studies comparing Bioplas to other materials could be found. Thus, the authors suggest further complementary studies given the promising properties of such new materials.

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