Kufa Journal of Engineering
Vol. 15, No. 1, January 2024, P.P. 19-29
Article history: Received 30 August 2023, last revised 15 September 2023, accepted 15 September 2023

THE INFLUENCE OF SINTERING TEMPERATURE, SLIDING SPEED, AND SLIDING TIME ON THE WEAR RATE OF YTTRIUM-TETRAGONAL ZIRCONIA POLYCRYSTALS (3Y-TZP) FOR DENTAL APPLICATION

Karrar A. Mzedawee[1] and Iman J. Abed[2]

[1] Department of Materials Engineering, Faculty of Engineering, University of Kufa, Iraq, Najaf, Iraq- E-mail: k9arrartaa@yahoo.com

[2] Department of Materials Engineering, Faculty of Engineering, University of Kufa, Iraq, Najaf, Iraq- E-mail: iman.alshaibani@uokufa.edu.iq

https://doi.org/10.30572/2018/KJE/150102

ABSTRACT

In this thesis, the samples of dental zirconia were sintered to various temperatures (1250,1350, and 1450) °C, and subjected to friction between them in saliva at two different sliding speeds (200 and 400 revolutions per minute) and in various periods (10, 20, and 30 minutes) by using pin on disc wear testing machine, the wear rate was affected by several factors (sintering temperature, sliding speed, and sliding time). Where the rate of wear decreased by the increase of one of these factors with the stabilization of the other two factors.

KEYWORDS: Ceramic, Zirconia, Friction, Wear Rate, Wear, Sintering Temperature, Sliding Speed, Sliding Time.

Article information: This manuscript was handled by Abbas Al-Hdabi, Managing Editor.

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1. INTRODUCTION

In recent years, ceramics restorative materials have attracted considerable interest in dental applications (Zhang et al., 2013) and (Tong et al., 2016). Zirconia, specifically yttrium-stabilized tetragonal zirconia polycrystal (Y-TZP), was chosen as a core material to help prevent bulk fracture of ceramic restorations (Rekow et al., 2011). An important property of zirconia is its transformation toughening and an ability to slow crack propagation and improve fracture resistance. Zirconia has a flexural strength of 900 to 1200 MPa and a fracture toughness of 9 to 10 MPa・m0.5.5-7 With its superior mechanical properties, zirconia has been used for multiunit and complete arch frameworks, implant abutments, and complex implant superstructures for fixed and removable prostheses (Janyavula et al., 2013). The high hardness of Y-TZP ceramic has gained increasing attention to the wear of tooth enamel. Although some *in vitro* studies have shown that the monolithic zirconia crown with the highly polished surface has less wear on tooth enamel and even lower than the Y-TZP ceramic with decorative ceramic (Tang et al., 2021). To date, a limited number of clinical studies have concentrated on the wearing of the monolithic zirconia crown on natural teeth. The quantitative methods used to measure the wear of the teeth have reported contradictory results (Tang et al., 2021; Pathan et al., 2019; Janyavula et al., 2013; Mitov et al., 2012; Stober et al.,2014). Zirconia" quickly became popular due to a number of benefits, including superior mechanical qualities as compared to other ceramic systems, good esthetics, and biocompatibility. Zirconia has become the preferred innovative restorative due to the mechanical failures in metal-ceramic restorations and the rising pricing of precious alloys (Mundhe et al., 2015). One of the most highly stable materials is the ceramics made of tetragonal zirconia stabilized with yttrium (3Y-TZP), which makes the ceramic crowns and settled dental prostheses use as core materials for different medical and engineering applications (Janyavula et al., 2013). Wear is deterioration that results from many sources and is characterized by surface alterations and volume loss with usage. It is important to note that the oral medium is complicated, thus in order to fully comprehend each wear mechanism, it is important to realize that food, changes in temperature and pH, chewing frequency and force, as well as antagonistic forces, all have effects on the surfaces of restorative materials. During a lifetime, it is normal to expect some physiological tooth wear. Each person's rate of advancement is different, and no every wear of tooth want to treat it. The wear of the teeth will be unhealthy if it must be above the usual stage for the age of the individual and interfere with the individual's conception of their own luxury (Jitwirachot et al., 2022). Dental ceramics are a popular choice for oral rehabilitation due to superior physical properties and durability against wear (Schlueter et al., 2020).

2. EXPERIMENTAL PART

2.1. Material

In this research has been used the Dental Direct Zirconia Block from a German company as shown in Table 1.

Table 1. Summary of materials used, their manufacturer and chemical components.

Materials	Chemical components (%)	Typical properties of sintered body
DD Bio ZW High strength zirconia	$ZrO2 + HfO2 + 3Y2O3 > 99$ $Al2O3 < 0.5$ Other oxide < 1	Density > 6.05 (g/cm^3)

The samples coded with limited symbols to facilitate their description and identification to (A400, A200, B400, B200, C400, and C200), Where the group (A) refers to samples sintered at 1250°C, group (B) refers to samples sintered at 1350°C, and group(C) refers to samples sintered at 1450°C. While (400 and 200) refer to sliding speed in revolution per minute(rpm).

2.2. Methods

1- Bring the block of zirconia from Dental Direct Company, the samples were cut into the required shapes by the CAD-CAM machine (12 pins and 12 discs), as the dimensions of the pins are (height is 12mm and diameter is 12 mm) and for the discs are (height is 12 mm and diameter is 30 mm).

2- Then the samples were taken to be divided into three groups, each group consisting of (4 pins and 4 disks) to be sintered at different temperatures, as shown in Figs. 1, 2 and 3 which refer to the sintering process of each group.

3- The samples were weighed and subjected to a wear test by Pin-on-disc wear testing machine in saliva under the influence of a load of 100 Newton, with two speeds (400 and 200 revolutions per minute) and a period of (10, 20, and 30 minutes), in each group there are many states:

- Two pins rubbed against two discs from the vertical side of each of the pin and disc (the circular area) at a speed of 400 revolutions per minute, to be divided into (10, 20, and 30 minutes).

- Two pins rubbed against two discs from the vertical side of each of the pin and disc (the circular area) at a speed of 200 revolutions per minute, to be divided into (10, 20, and 30 minutes).

The samples were weighed again to find out the weight loss that occurred as a result of wear and to calculate the wear rate.

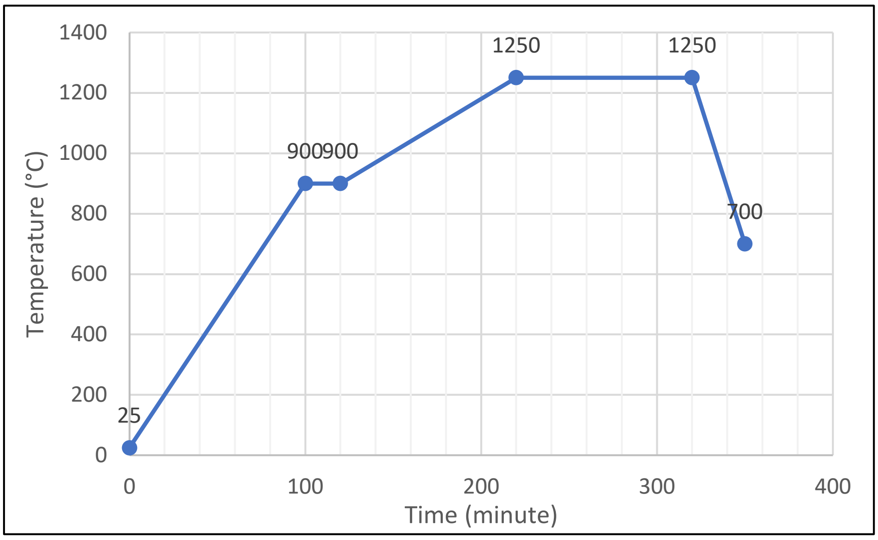

Fig. 1. Sintering diagram to 1250°C.

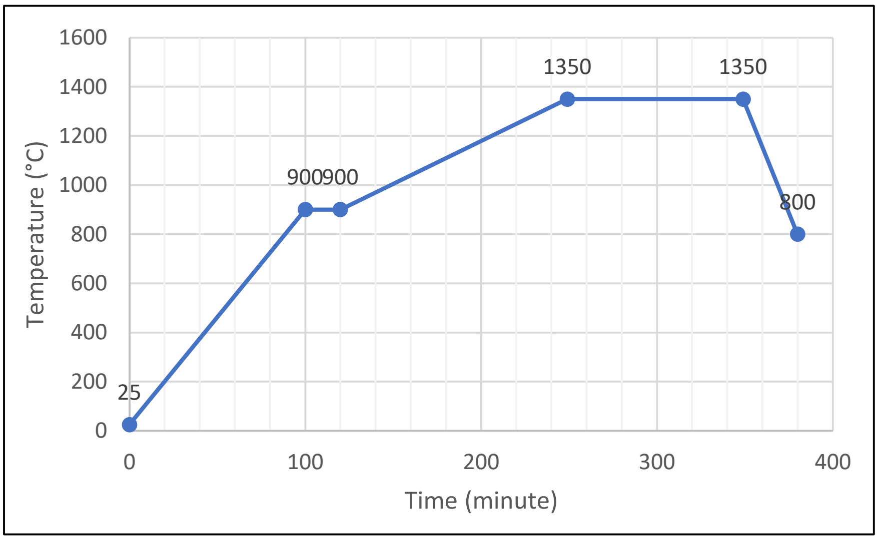

Fig. 2. Sintering diagram to 1350°C.

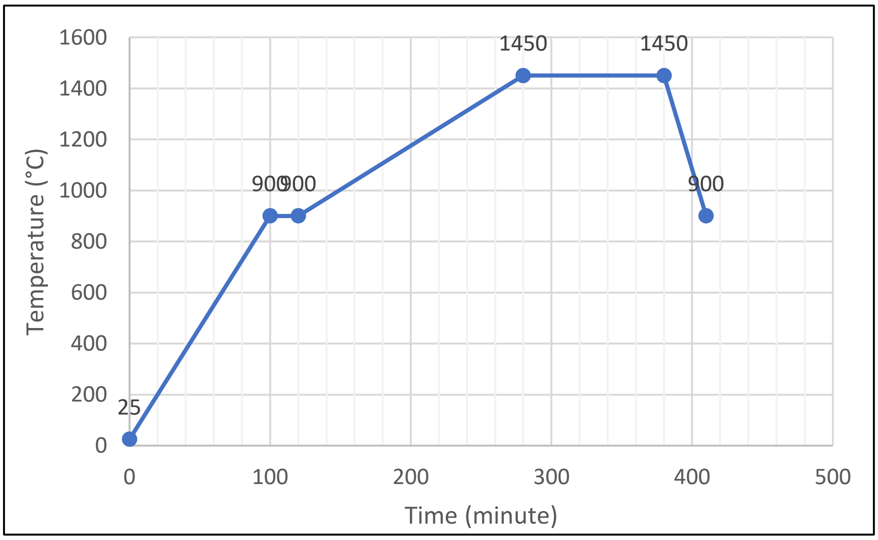

Fig. 3. Sintering diagram to 1450°C.

2.3. Tools

2.3.1. CAD/CAM machine

The computer-aided design / computer-aided manufacturing machine used to form the wear samples in required shapes (pins: 12 mm high, 12 mm diameter) and (disks: 12 mm high, 30 mm diameter). The main constituents are the computer (to input the data of the design in a program) and the machine (to manufacture the shape of the sample according to the design), CAD/CAM machine is finding at (Materials Engineering Department/college of Engineering / University of kufa), as shown in Fig. 4.

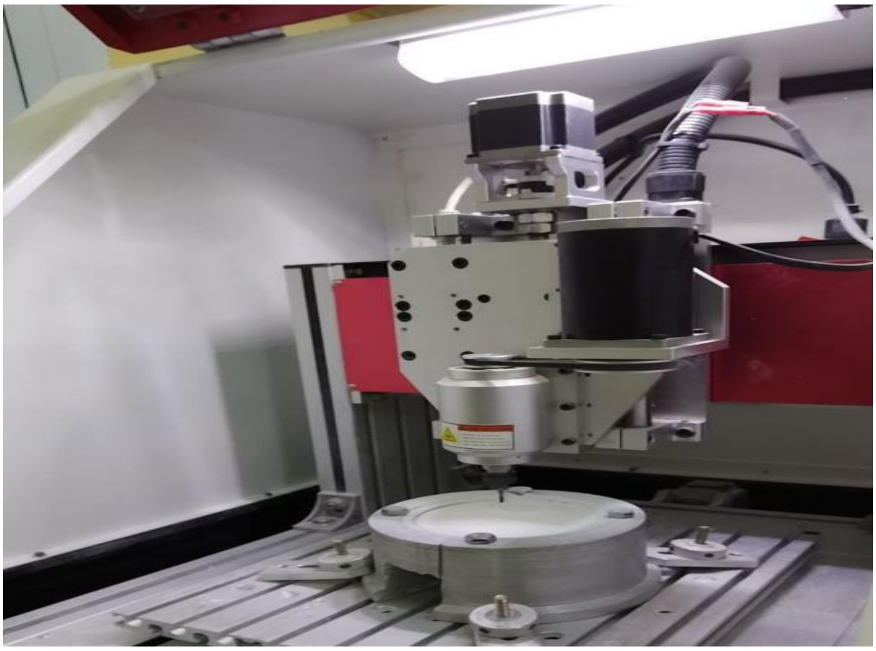

Fig. 4. CAD/CAM machine

2.3.2. Sintering furnace

It is an electrical heating device to heat the powder-compact to reduce the porosity and improve some mechanical properties, where the hardness, translucency, and density are increasing. The heating obtains to temperature by about (35-65) % of the melting point of powder-compact. this furnace at nanotechnology division/ materials engineering department/ faculty of engineering/ university of Kufa.

2.3.3. Digital electronic balance

This electronic device is used for measuring the weight of small samples with a digital screen to show the results, (Model: Denver Instrument Made in Germany), It is located at Materials Engineering Department /the faculty engineering/ Kufa University.

2.3.4. Wear testing machine (Pin on disc)

This machine is used for measuring the wear in materials by applying a load on the pin which presses the disc, the pin rotates on a disc with a limited rotation speed and limited time, the machine had been made locally in the mechanical engineering department /the faculty engineering /Kufa University. It contains an electronic screen to enter the speed and time required for the machine to start working, the pin is fixed to the disk that rotates, causing wear on the connected surfaces as a result of friction, so that the less hard body will be worn. The wear rate can be calculated from using the Equations (1 and 2).

$$WR = \Delta W / \rho 2\pi rNt \tag{1}$$

$$\Delta W = W0 - Wf \tag{2}$$

Where:

WR: The wear rate in (cm3/cm)

ρ: Density of material in (gm/cm3)

r: Radius from the center of the pin to the center of the disc in (cm)

N: Sliding Speed of pin on disc in (rpm)

t: Time of sliding in (min)

ΔW: Weight Loss in (gm)

W0: Starting weight in (gm)

Wf: Final weight in (gm)

and radius of track (r) are 0.517 cm for pin and disc of which sintered at 1250°C, 0.531 cm for pin and disc of which sintered at 1350°C,0.5355 cm for pin and disc of which sintered at 1450°C, density of sintered zirconia =6 gm/cm^3.

2.4. RESULTS AND DISCUSION

2.4.1. Influence of the sliding speed on the wear rate for (3Y-TZP)

It is possible to calculate the effect of sliding speed on the wear rate by making the time and temperature constant for several samples by using equations (1 and 2) and Table 2. To find the wear rate as in Tables 3, 4, and 5.

Table 2. Represent decrease the weight with time.

Sample	Original weight (gm)	Weight (gm) after 10 min	Weight (gm) after 20 min	Weight (gm) after 20 min
A400	4.3804	4.3473	4.3396	4.3312
B400	4.3818	4.3651	4.3593	4.352
C400	4.3795	4.3633	4.3581	4.3521
A200	4.3793	4.3561	4.3481	4.3462
B200	4.3763	4.3621	4.3577	4.352
C200	4.3746	4.3608	4.3573	4.3532

Table 3. Shows wear rate for sample which sintered at 1250°C and subjected to friction after 30 minute.

Sliding Speed (rpm)	Samples	Wear Rate (WR) in (cm^3/cm)
200	A200	2.831*10^(-7)
400	A400	2.104*10^(-7)

Table 4. Shows wear rate for sample which sintered at 1350°C and subjected to friction after 30 minute.

Sliding Speed (rpm)	Samples	Wear Rate (WR) in (cm^3/cm)
200	B200	2.024*10^(-7)
400	B400	1.214*10^(-7)

Table 5. Shows wear rate for sample which sintered at 1450°C and subjected to friction after 30 minute.

Sliding Speed (rpm)	Samples	Wear Rate (WR) in (cm^3/cm)
200	C200	1.768*10^(-7)
400	C400	1.132*10^(-7)

As shown from the results the wear rate reduces with increasing the sliding speed, by making the time and sintering temperature constant for each group, this agrees with (Lambrechts at el., 1989).

2.4.2. Effect of sintering temperature on wear rate of (3Y-TZP)

It must to compare the wear rate of the samples that were sintered at a temperature of (1250, 1350, and 1450)°C under the same conditions. It can be noticed from Fig. 5 and Fig. 6, decreasing in the wear rate with increasing sintering temperature and the relationship between them is not a linear. This result agrees with (Gupta, 2019), because the increasein the hardness and decrease in the porosity with increased sintering temperature in a limited range, will lead to reducing the loss of material grains which leads to a decrease in the wear rate.

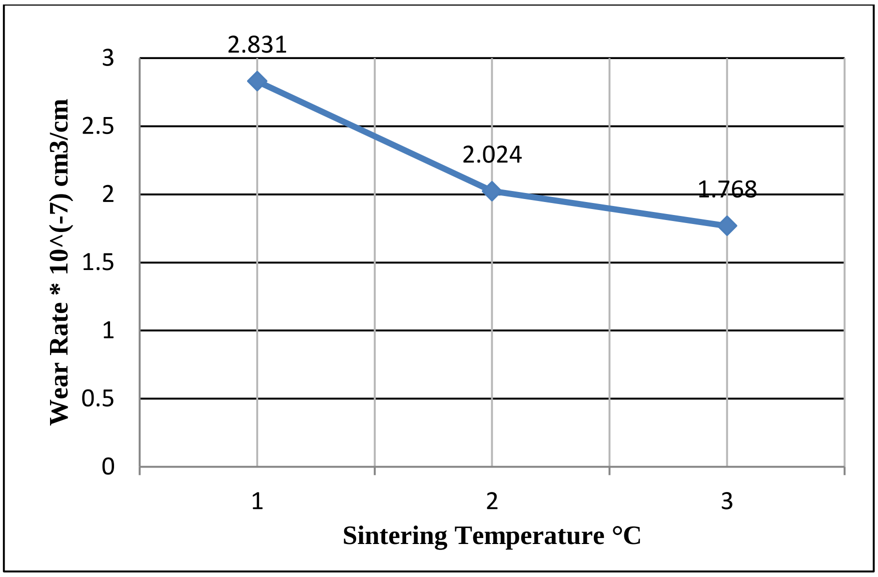

Fig. 5. Wear rate vs Sintering temperature, where (1 = 1250°C,2=1350°C,3=1450°C) at 200 rpm and 30 minute.

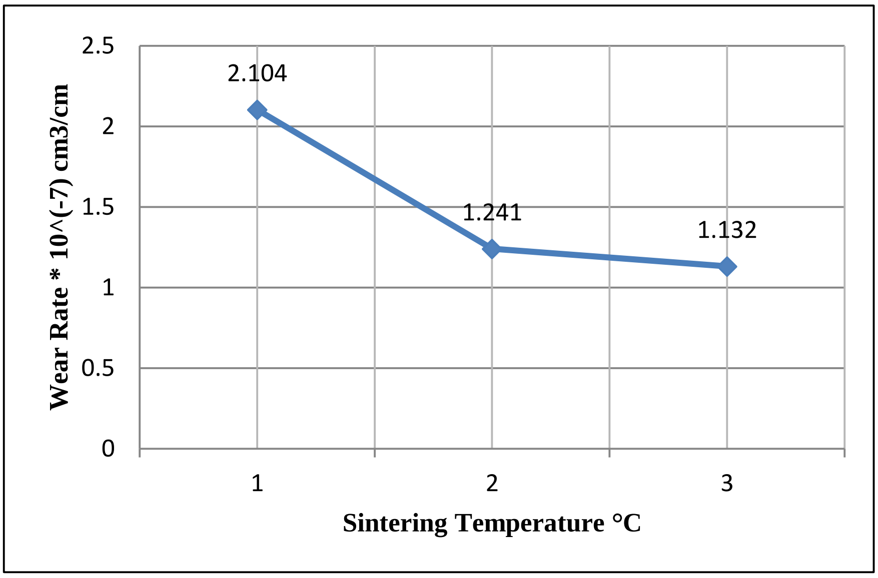

Fig. 6. Wear rate vs Sintering temperature, where (1 = 1250°C,2=1350°C, 3= 1450°C) at 400 rpm and 30 minute.

2.4.3. Influence time of sliding on the wear rate for (3Y-TZP)

The effect of the wear rate with the sliding time as shown in the Fig.7. At the other conditions were to be constant such as the speed and the sintering temperature, the samples will be taken whose sintering degree is 1250°C and the sliding speed is 200 revolutions per minute, and note the wear rate on them at different times (10, 20, and 30) minutes and by drawing the relationship between wear rate and time. Also, samples were taken whose sintering degree was 1350°C, and the sliding speed was 200 revolutions per minute, it can be noticed that the wear rate on them at different times (10, 20, and 30) minutes, and by drawing the relationship between the wear rate and time, as in the Fig. 8. From Figs. 7 and 8, the results refer to the relationship isn't linear and also a decrease in the wear rate with an increase in the sliding time for the samples which have the same sintering temperature and sliding speed, due to reduce the coefficient of friction gradually with time.

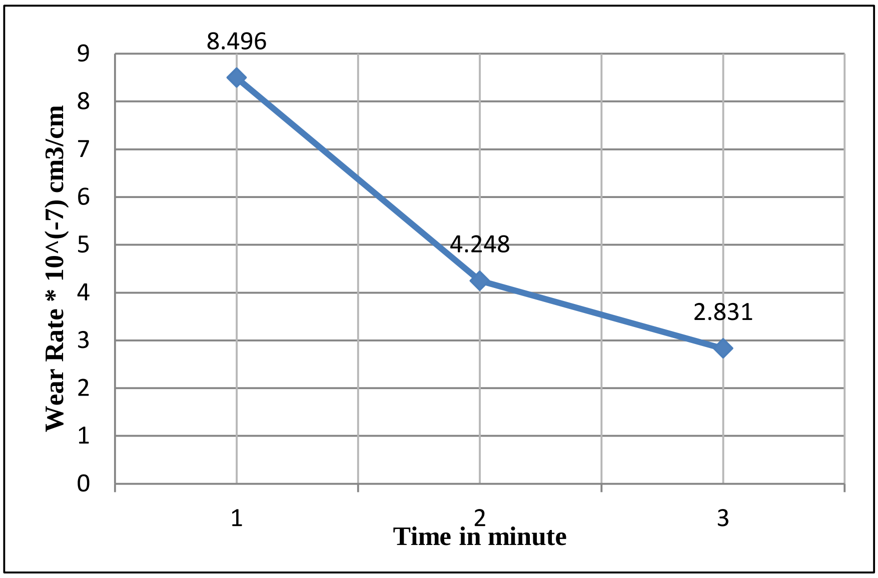

Fig. 7. Wear rate vs sliding time, where (1 = 10, 2=20, 3= 30) minute at 200 rpm and 1250°C.

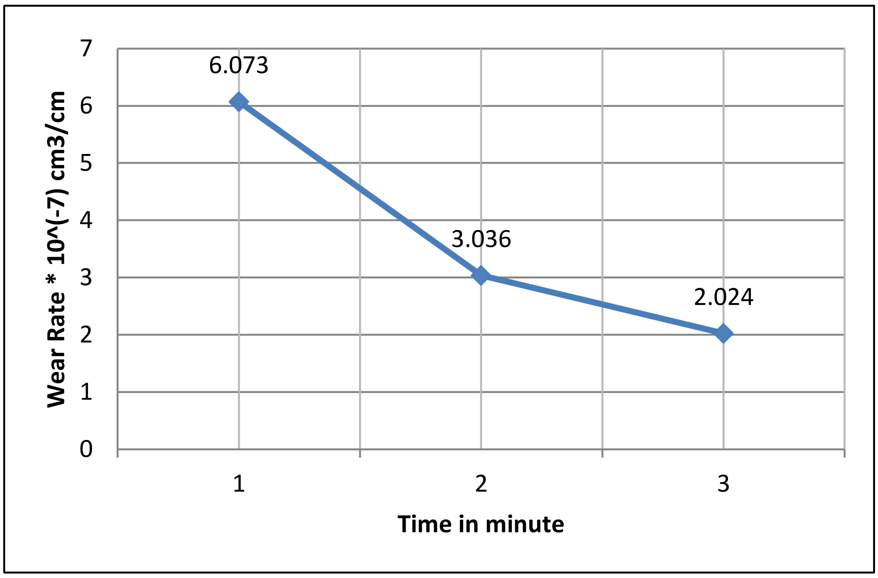

Fig. 8. Wear rate vs sliding time, where (1 = 10, 2= 20, 3= 30) minute at 200 rpm and 1350°C.

3. CONCLUSIONS

1- The wear rate of "3Y-TZP zirconia" effects with many factors such as sliding speed, sintering temperature, and sliding time.

2 - The wear rate reduces with the rising of the sliding speed, when the sintering temperature and sliding time are being constant.

3- Decreasing in the wear rate with increasing of the sintering temperature, when the sliding speed and sliding time are being constant.

4- Decreasing in the wear rate with increasing of the sliding time, when the sintering temperature and sliding speed are being constant.

REFERENCES

Gupta, J., (2009). Mechanical and wear properties of carburized mild steel samples (Doctoral dissertation). https://core.ac.uk/reader/53187220

Janyavula, S., Lawson, N., Cakir, D., Beck, P., Ramp, L.C. and Burgess, J.O., (2013). The wear of polished and glazed zirconia against enamel. The Journal of prosthetic dentistry, 109(1), pp.22-29.

Jitwirachot, K., Rungsiyakull, P., Holloway, J.A. and Jia-Mahasap, W., (2022). Wear behavior of different generations of zirconia: present literature. International Journal of Dentistry, 2022.

Lambrechts, P., Braem, M., Vuylsteke-Wauters, M. and Vanherle, G., (1989). Quantitative in vivo wear of human enamel. Journal of dental research, 68(12), pp.1752-1754.

Mitov, G., Heintze, S.D., Walz, S., Woll, K., Muecklich, F. and Pospiech, P., (2012). Wear behavior of dental Y-TZP ceramic against natural enamel after different finishing procedures. Dental materials, 28(8), pp.909-918.

Mundhe, K., Jain, V., Pruthi, G. and Shah, N., (2015). Clinical study to evaluate the wear of natural enamel antagonist to zirconia and metal ceramic crowns. The Journal of prosthetic dentistry, 114(3), pp.358-363.

Pathan, M.S., Kheur, M.G., Patankar, A.H. and Kheur, S.M., (2019). Assessment of antagonist enamel wear and clinical performance of full-contour monolithic zirconia crowns: one-year results of a prospective study. Journal of Prosthodontics, 28(1), pp. e411-e416.

Rekow, E. D., Silva, N. R. F. A., Coelho, P. G., Zhang, Y., Guess, P., and Thompson, V. P. (2011). Performance of dental ceramics: challenges for improvements. Journal of dental research, 90(8), 937-952.

Schlueter, N., Amaechi, B.T., Bartlett, D., Buzalaf, M.A.R., Carvalho, T.S., Ganss, C., Hara, Huysmans, A.T., Lussi, M.C.D., Moazzez, A.R., and Vieira, A.R., (2020). Terminology of erosive tooth wear: consensus report of a workshop organized by the ORCA and the Cariology Research Group of the IADR. Caries research, 54(1), pp.2-6.

Stober, T., Bermejo, J.L., Rammelsberg, P. and Schmitter, M., (2014). Enamel wear caused by monolithic zirconia crowns after 6 months of clinical use. Journal of oral rehabilitation, 41(4), pp.314-322.

Tang, Z., Zhao, X., and Wang, H. (2021). Quantitative analysis on the wear of monolithic zirconia crowns on antagonist teeth. BMC Oral Health, 21, pp.1-11.

Tiwari, R.A.J.A.N., Sameer, S. and PBS, S., (2014). Tribological behaviour study of ceramic composites (Doctoral dissertation).

Tong, H., Tanaka, C. B., Kaizer, M. R., and Zhang, Y. (2016). Characterization of three commercial Y-TZP ceramics produced for their high-translucency, high-strength and high-surface area. Ceramics international, 42(1), 1077-1085.

Zhang, Y., Sailer, I., and Lawn, B. R. (2013). Fatigue of dental ceramics. Journal of dentistry, 41(12), 1135-1147.