

The Role of Additives in Enhancing Corrosion and Wear Resistance of Dental Amalgam

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Abstract

It is well established now that alloying elements play an important part in controlling the behaviour of dental amalgam. The primary constituents are Ag, Sn, Cu, and sometimes Zn which were traditionally carefully chosen for certain specific characteristics. In this work, however, (0.5-1) % ZnO and TiO₂ were added separately and together to the control sample (low copper). Tafel extrapolation technique was used to investigate the corrosion behavior, while (Pin-on-Disc) wear test was also conducted. The corrosion current density of hybrid sample was only 41% of the corresponding value of the control. While the weight loss in the wear test of the same sample was 14% of the corresponding value of the control sample.

Keywords: Dental amalgam, TiO₂, ZnO, hybrid, corrosion behaviour, wear resistance

1. Introduction

Dental amalgam is an alloy originally containing about 70% silver, 25% tin, with smaller amounts of copper and sometimes zinc mixed with mercury. This composition varied over the years. They are malleable, durable, and more affordable than gold or composites (N.A. Aron, 2013).

There are many attempts to improve properties of dental amalgam by using treatment of amalgam alloy powder or addition of some materials such as In, Au, Pa and organic materials. One of the latest additive materials are Palladium (N. B. Tolou *et al*, 2013). Another new additive material was used Ag-Cu nanopowder (K. H. Chung *et al*, 2008).

Restorative wear is a natural and unavoidable physiological problem resulting from the fact that dental materials are subjected to variation factors associated with mastication and to the chemical and thermal aggressive environments of the oral cavity. In the case of dentures for instance, this variation occurs within seconds, imposing thermal stresses (J. Zheng and Z.R. Zhou, 2007; J. Zheng *et al*, 2003). The incidence of stresses together with the relative motion of contacting surfaces results in restorative wear. Restorative wear has multi-factorial origin involving the interplay of abrasive, tribochemical and fatigue wear (J. Zheng and Z.R. Zhou, 2007; C. G. Figueiredo *et al*, 2013).

One of the primary conditions of any metal used in the mouth is that it must not produce corrosion products that may be harmful to the body. Corrosion is a more serious matter which probably significantly affect the structure

and mechanical properties. The heterogeneous, multiphase structure of dental amalgam makes it prone to corrosion. Electrolytic cells are readily set up in which different phases form the anode and cathode and saliva provides the electrolytes (M. Fathi and V. Mortazavi, 2004; K. J. Anusavice, 1996; J. F. McCabe and A. W. Walls, 2008). Hence, these amalgams undergo galvanic corrosion, local corrosion (Ag-Hg vs. Ag-Sn-Cu or Sn-Hg phase), crevice corrosion and stress corrosion (L.Y. Ghassan, 2011). The aim of this work is to investigate the effect of TiO₂ and/or ZnO composites on corrosion and wear behaviour of dental amalgam.

2. Experimental Procedure

2.1 Materials and sample preparation

Powders of materials used in this work are shown in **Table 1**. It is an admixed amalgam (Rubygam High Ng Powder Amalgam) and (Rubygam Powder Amalgam). It consists of micro-fine lathe-cut very thin needle-shaped cut particles. The size of TiO₂ particles was measured by Particle size analyzer was <80 µm, and the size of the ZnO was (80nm-20µm) as shown in Fig (1). The purity of mercury was 99.99% and its ratio was (1.03:1).

(0.5-1)% TiO₂ and ZnO were added separately and together. An amalgamator was used to mix the powder and mercury. The amalgam paste was condensed and then compressed by 14 MPa for 85 seconds into a steel die which has 6 holes, each hole had a cylindrical container with the diameter and height of 4.0 ± 0.1mm and 8.0 ± 0.1mm, respectively. Samples were then taken out of the die after 30 min and soaked in an incubator at 37 ± 1°C. Corrosion and wear tests were carried out in a synthetic

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Table 1 Details of used materials

S. No.	S. code	wt. %					
		Ag	Cu	Sn	Zn	ZnO	TiO ₂
1	Low copper	71	3.3	25.7	-	-	-
2	High copper	45	24	30.5	0.5	-	-
3	High copper +1% ZnO	44.55	23.76	30.195	0.495	1	-
4	High copper +1% TiO ₂	44.55	23.76	30.195	0.495	-	1
5	High copper +1% hybrid	44.55	23.76	30.195	0.495	0.5	0.5

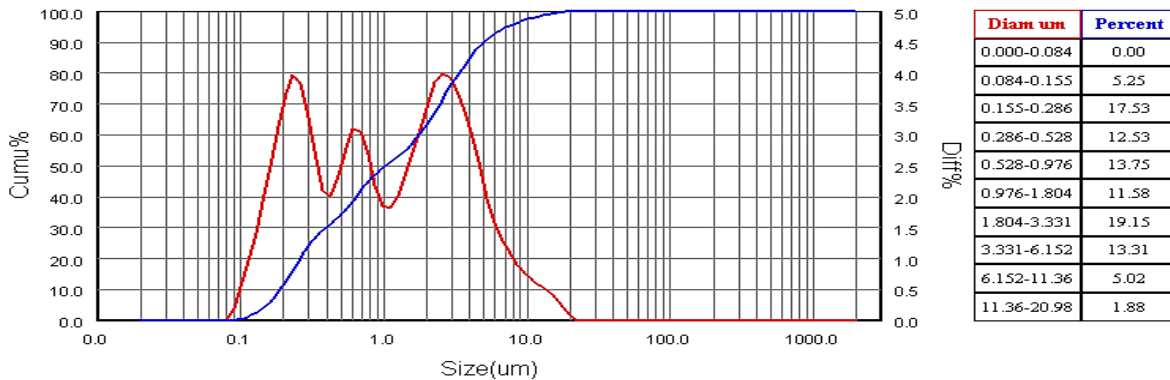


Fig. 1 Particle size distribution of ZnO

Table 2 Chemical composition of synthetic saliva

No.	Constituent	gm/l
1	KCl	1.5
2	NaHCO ₃	1.5
3	NaH ₂ PO ₄ H ₂ O	0.5
4	KSCN	0.5
5	Lactic acid	0.9



Fig. 2 Wear test apparatus

saliva, which closely resembles natural saliva, whose composition is shown in **Table 2** (H. H. Jaber, 2007). The pH solution was 6.7 at 37°C temperature.

2.2 Corrosion test

Tafel extrapolation method was adopted to determine the corrosion current densities. A scan rate of 0.4 mA. Sec⁻¹ was used. The solution was saliva at 37± 1°C. Samples were tested after storing for 7 days at 37± 1°C in an incubator. Samples were manipulated in such a way that only the surface (1 cm²) is exposed to saliva.

2.3 Wear test

The wear apparatus is a rotational type micro-tester (Pin-on-Disc) MT 4003 version 10 was adopted, Fig. (2). The diameter of the circular track was 12.5 mm. A martensitic Steel disc was used with minor carbides and austenite of Ra=0.265 μm and HV= 852 (ASTM Standard, 2000). The test was carried out using 5N load. Disc rotates at a constant speed of 150 rev/min. Samples were examined after grinding of up to (2500). Wet wear test was conducted in saliva of composition shown in **Table 2**. To determine the weight loss of amalgam a digital balance

(Denver Instrument) with a resolution of 0.1 mg was used for weighting the amalgam before and after the wear process

3. Results and discussion

The polarization curves of amalgam alloys are shown in Figs. (3-7). The related corrosion current densities and corrosion potentials are listed in **Table 3**.

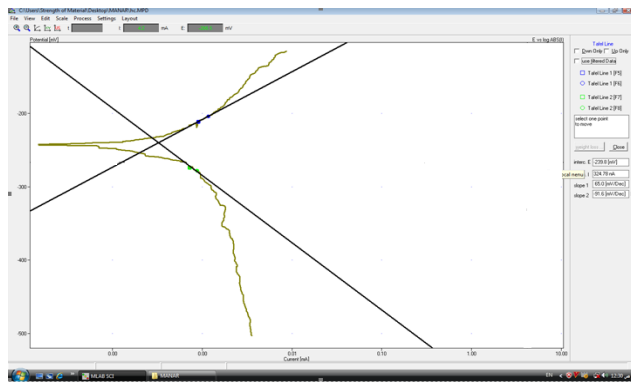


Fig. 3 Polarization curve of low copper amalgam in synthetic saliva at 37±1 °C

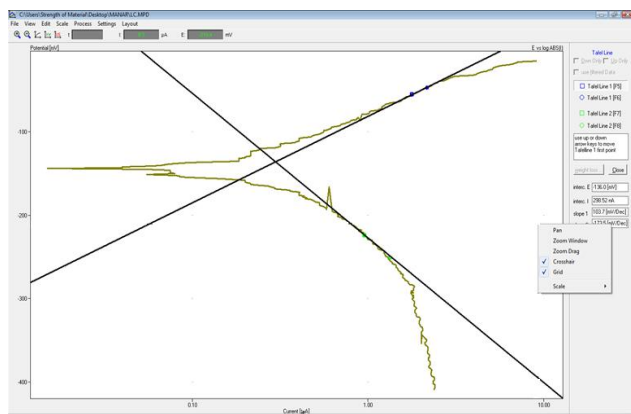


Fig. 4 Polarization curve of high copper amalgam in synthetic saliva at 37±1 °C

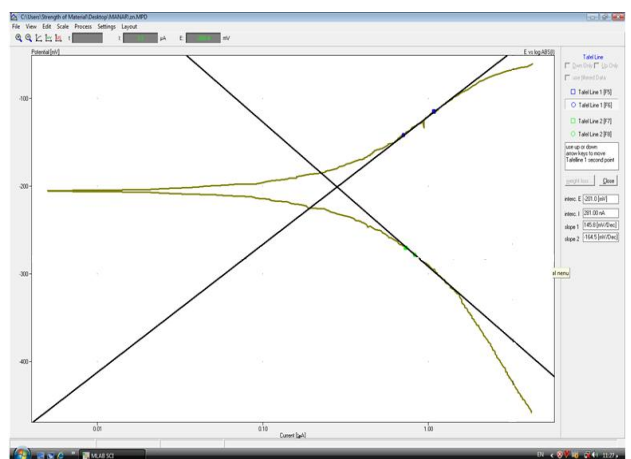


Fig. 5 Polarization curve of high copper +1%ZnO amalgam in synthetic saliva at 37±1°C.

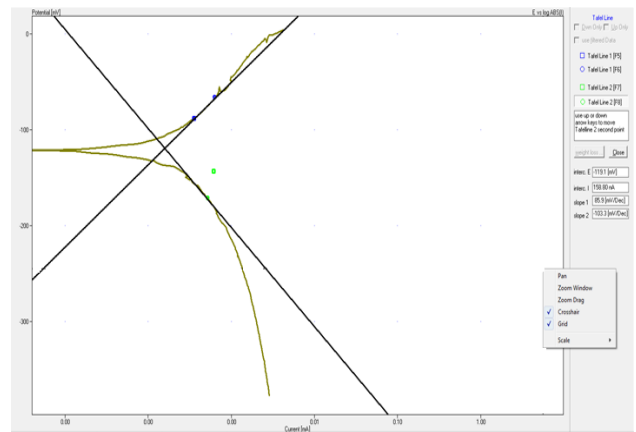


Fig.6 Polarization curve of high copper +1%TiO₂amalgam in synthetic saliva at 37±1 °C

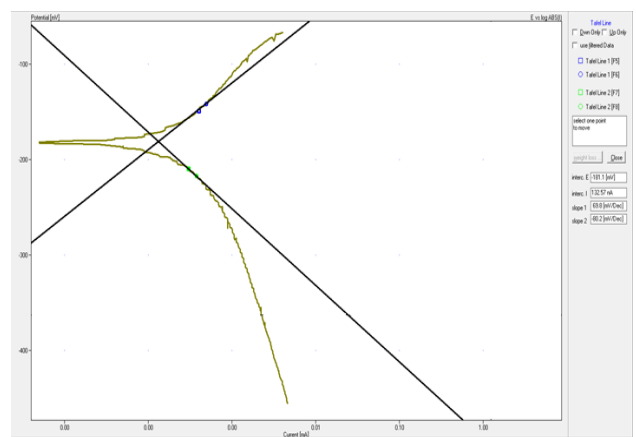


Fig. 7 Polarization curve of high copper +1% hybrid amalgam in synthetic saliva at 37±1 °C

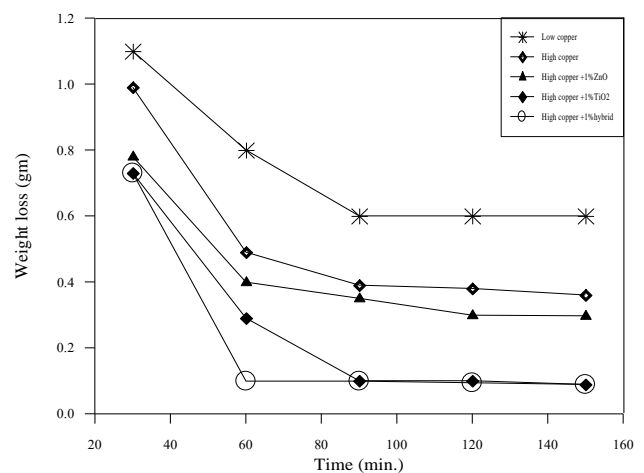


Fig.8 Weight loss as a function of exposure time in saliva

The corrosion current density of the control was 325 nA/cm², Fig. (3). However, when copper content was increased to (24%) instead of (3.3%) The corrosion current density reduced to 299 nA/cm², Fig. (4). This improvement is expected since copper was originally added to the amalgam to enhance corrosion resistance. Due to elimination of the most corrodible phase Sn₇₋₈Hg

Table 3 Corrosion potential (E_{corr}), corrosion current density (i_{corr}), corrosion rate of the amalgams

No.	Amalgam	E_{corr} (mV)	i_{corr} (nA/cm ²)	Corrosion Rate (mpy)
1	Low copper	-239.8	325	0.342
2	High copper	-136	299	0.26
3	High copper +1%ZnO	-201	281	0.235
4	High copper +1%TiO ₂	-119.1	159	0.135
5	High copper +1%hybrid	-181	133	0.11

(γ_2) (M. Fathi and V. Mortazavi, 2004). Increasing copper content however, associated with the formation of (η) phase (Cu_6Sn_5) which is slightly better corrosion resistance than (γ_2) phase. This is probably why the observed improvement in high copper was little.

For further improvement an attempt was carried out by adding (1% ZnO) to the high copper sample, Fig. (5). The observed corrosion current density was 281 nA/cm². Which is about (86% with respect to the control sample current density) that the addition of ZnO to the amalgam improved the compressibility (N. Yahya, 2013).

However, if this is the case, then it can be concluded that the hardness is increased as well. This reflected positively as a reduction of wear resistance because the wear rate is inversely proportional to the hardness. Increasing compressibility by such a nanofiller probably enhance diffusivity of the building protective layer against corrosion. This enhancement may also be attributed to the refining of the grains, since foreign particles may act as nucleating sites in addition to the prevention grain growth. The addition of 1%TiO₂ also improved corrosion resistance, since it reduces the corrosion current density from 325nA/cm² to 159nA/cm² (which is about 48% with respect to the control sample current density), Fig (6). This result is in contrary to the finding of Tolou et al (N. B. Tolou et al, 2013). The reduction of corrosion current density and strength observed by Tolou et al results from the high addition of TiO₂ which caused an increase in porosity of the sample. A further effect was made by adding TiO₂ and ZnO together. A high reduction in corrosion current density was observed, Fig. (7). It was only (41%) of the corresponding value of the control sample.

Wear behaviour of the examined samples measured in terms of weight loss and shown in Fig. (8). In the early stages of the test, however, the lost decreases with time. This is may be attributed partly to the fact that hardness of the disc (steel) is about four times higher than that of the pin (sample). Therefore a possibility transforming of the pin material to the steel (smearing), and the friction now become between amalgam on amalgam. Decreasing weight loss with time was also observed by Davis (J. R. Davis, 2003).

A significant reduction in weight loss observed when both TiO₂ and ZnO were added together. It was only (14%) with respect to the control sample. According to the hardness of the samples these results are expected since the wear rate is inversely proportional to the hardness.

Conclusion

1. An improvement in corrosion resistance was obtained. The corrosion current densities were reduced to about 41% of the corresponding control sample.
2. Wear resistance was also enhanced significantly. The weight loss reduced to a value of 14% compared to the control sample.

References

- N.A. Aron, 2013, health implications of dental amalgam, PhD thesis, Karolinska Institute, Stockholm, Sweden.
- N. B. Tolou, M. H. Fathi, A. Monshi, V. S. Mortazavi, F. Shirani and M. M. Sichani, 2013, the effect of adding TiO₂ nanoparticles on dental amalgam properties, Iranian Journal of Materials Science & Engineering Vol. 10, No. 2, pp. 46-56.
- K. H. Chung, L.Y. Hsiao, Y. Sh. Lin and J.G. Duh, 2008, morphology and electrochemical behaviour of Ag-Cu nanoparticle-doped amalgams, Acta Biomater., Vol. 4, pp.717-724.
- J. Zheng and Z.R. Zhou, 2007, friction and wear behaviour of human teeth under various wear conditions, Tribology International, Vol. 40, pp. 278-284.
- J. Zheng, Z.R. Zhou, J. Zhang, H. Li and H. Yu, 2003, on the friction and wear behaviour of human tooth enamel and dentin, Wear, Vol. 255, pp. 967-974.
- C. G. Figueiredo, A. Monteiro, M. Guedes, A. Maurício, A. P. Serro, A. Ramalho and C. Santos, 2013, effect of feldspar porcelain coating upon the wear behaviour of zirconia dental crowns, Wear, Vol. 297, pp. 872-877.
- M. Fathi and V. Mortazavi, 2004, a review on dental amalgam corrosion and its consequences, Journal of Research in Medical Sciences, vol. 1, pp. 42-51.
- K. J. Anusavice, 1996, Phillips Science of Dental Materials. 10th ed. Pennsylvania, USA, W.B. Saunders Company.
- J. F. McCabe and A. W. Walls, 2008, applied dental materials, 9th Edition, Blackwell publishing, UK.
- L.Y. Ghassan, 2011, corrosion of amalgams in oral cavity, Journal of Engineering, Vol. 17, No.2, PP.366-372.
- H. H. Jaber, 2007, improvement of mechanical and corrosion properties of dental amalgam alloys, PhD thesis, University of Technology, Iraq
- ASTM Standard: G 99 – 95a, Standard test method for wear testing with a pin-on-disc apparatus, 2000.
- N. Yahya, P. Puspitasari and N. R. A. Latiff, 2013, Hardness Improvement of Dental Amalgam Using Zinc Oxide and Aluminium Oxide Nanoparticles, Advanced Structured Materials Vol.29, pp.9-32 .
- J. R. Davis, 2003, handbook of materials for medical devices, ASM International, Ch. 12, pp.283-315.