Thin Film Metallic Glass Coating for Steel Bearing Applications

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Abstract

Most metals that are used in all applications have a crystalline structure and this makes the metals to be more ductile. This report shows the manufacturing and some physical properties of a metallic glass (amorphous metal), particularly Zr-Cu-Al-Ni and W-Ni-B based metallic glass. Physical Vapour Deposition sputtering deposition is used to create this metallic glass with a hardened SUJ2 steel plate as the substrate to be deposited on. Hardness test shows the average hardness for Zr-Cu-Al-Ni and W-Ni-B to be 10.23 and 16.54 GPa respectively, with an average Young's modulus of 154.17 and 209.59 Gpa respectively. Adhesion test shows that it is still a challenge to find the optimal parameters to get the best adhesion

Introduction

Metal is such a ubiquitous material that we encounter in our life that we do not pay much attention to it. We have harnessed the power of metallurgy for thousands of years, however there are still many ways to enhance the quality of the metals that we produce as the strength of most metals used are 10^3-10^4 times lower than the calculated strength from metallic bonding alone (Wright, 2016). Most of this comes from the crystalline structure of the metal and the presence of slip planes that allow the structure to be able to easily slip in this certain direction. However as metallic glass is amorphous it does not have a clear repeating structure thus the presence of slip planes is considerably reduced. Furthermore metallic glass has also been reported to increase corrosion resistance due to the amorphous structure and overall homogeneity (Lou, 2017).

The main goal for this work is to test the feasibility of utilizing thin film metallic glass as a coating in steel bearing application. Due to the amorphous structure the metal is harder, more wear resistant, having a less roughness and high surface smoothness and low friction coefficient (C. Zhang, 2012) (Yi-Cheng li, 2018) all of this is a desirable property in bearing applications.

Motivation

Bearing is a crucial mechanical component in a lot of applications, if it spins or moves there is a big probability that bearing is involved in that movement. And as it stands today, bearings need to be regularly maintained and lubricated but even then bearings could still fail due to corrosion and abrasion. The motivation behind this research is to develop a steel bearing that has a longer lifetime thus lowering maintenance and increasing reliability. The idea behind using metallic glass is mostly for their wear resistance which will help to sustain abrasion, the chemical resistance to resist corrosion and fouling, and their high surface smoothness and low friction coefficient which could reduce the need of lubrication but still being able to have less friction force sustained by the bearing. In whole this application of metallic glass could drastically improve the performance and reliability of bearings theoretically

My personal motivation to do this research stems from my own curiosity regarding material science and especially metals. This curiosity was sparked by the Materials Science course that I had to take in my sophomore year of chemical engineering. This course gave me some answers to phenomena that I had experienced in my life and explained to me why certain materials are used in certain applications. However this course also gave me more questions about the materials that we use and how to improve them and as a result I decided to take this topic for my special topic research work

Description of Research Work

The method involved in this report to manufacture the metallic glass is by high-power impulse magnetron sputtering (HIPIMS) physical vapour deposition (PVD) where a relatively high power density is supplied to the target in short pulses that span only microseconds, moreover a bias current was given to the substrate. This method gives a high density of deposited film on the substrate in comparison to conventional PVD methods (Stephan, 2019).

In this work the thin film metallic glass (TFMG) is made from a bulk metallic glass (BMG) target with the composition of Zr-Cu-Al-Ni and W-Ni-B with a thin Ti layer between the steel substrate and the metallic glass in hope to improve adhesion. As HIPIMS was used a notable racetrack pattern was observed on the target material.

Before sputtering began plasma cleaning was done. As we intend to vapourize the target the pressure is important variable to control and thus the chamber was placed under argon atmosphere and the working pressure when sputtering was kept a 5 mtorr (0.666 Pa) during the Ti sputtering and at 6 mtorr (0.799 Pa) for the sputtering of the target. The full list of parameter is given on **Table 4.1** below

Parameters	**Value**				
Target materials	Ti		Zr-Cu-Al-Ni		W-Ni-B
Power system	HiPIMS				
Power (W)	400		500		500
Working pressure (mTorr)	5		6		6
Ar flowrate (sccm)	20				
Deposition time (min)	2	5	60	45	45
Frequency (Hz)	250		250		200
Pulse time (μs)	100		100		80
Bias/plasma cleaning	(-600) – (-100)				
Applied bias (V)	-100				

Table 4.1 Sputtering Parameter

The sample made was then tested using nano indenter to find the average hardness and average Young's modulus the result is shown by **Table 4.2** below

Film materials	**Average hardness (GPa)**	**Average Young's Modulus (Gpa)**
Ti-ZrCuAlNi (5-45 min)	10.23	154.17
Ti-WNiB (5-45 min)	16.54	209.59

Table 4.2 Hardness and Young's modulus of sample

Further, the sample was also tested for how well the TFMG adheres to the substrate by doing an adhesion test that aims to delaminates the TFMG from the substrate by giving a large compressive force and thus creating an indentation. This test gives a qualitative data that we can draw a conclusion from. This is shown in **Figure 1**.

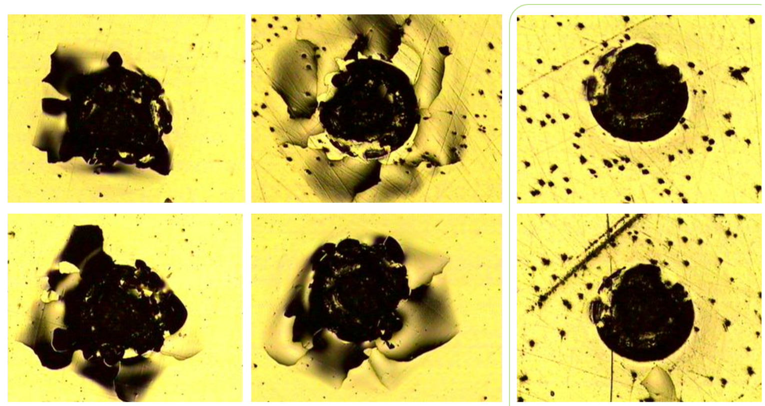

Figure 1. Adhesion test result

We can see from how the sample delaminates the sample that is highlighted in green has the best adhesion to the substrate. Even though some regions still show delamination in comparison to the other 2 samples, the highlighted sample shows the best adhesion property.

Conclusion

Tests conducted on the samples gives the result of average hardness for Ti-ZrCuAlNi and Ti-WNiB to be 10.23 and 16.54 GPa respectively, with an average Young's modulus of 154.17 and 209.59 Gpa respectively. Compared to a heat treated water quenched AISI 52100 bearing steel that has a hardness of 8.31 GPa and a Young's modulus range of 190-210 GPa (Zonen, 2013) we can conclude that the Ti-WNiB sample has higher hardness and comparable Young's modulus, however as shown this sample has poor adhesion quality. Meanwhile the Ti-ZrCuAlNi sample has a higher hardness but a lower Young's modulus.

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