Synthesis of Magnetic Nanoparticles for the Finishing of Biomedical Implants

Arthur Graziano[1], Bernadette A. Hernandez-Sanchez[2], Jason L. Townson[3], Ping Lu[2], Hitomi Yamaguchi[1], Tony Schmitz[1]

[1]Mechanical and Aerospace Engineering Department, University of Florida, Gainesville, FL

[2] Advanced Material Laboratory, Sandia National Laboratory, Albuquerque, NM

[3]Center for Micro-Engineered Materials, University of New Mexico, Albuquerque, NM

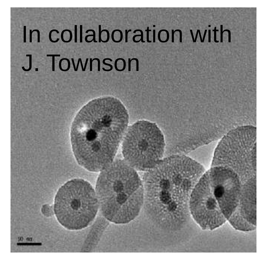
Graziano@ufl.edu

In order to improve lubrication and wear of prosthetic implants, a magnetic abrasive finishing (MAF) technique is implemented for the polishing of knee prostheses. An improvement in the tribological properties of the femoral component can be achieved by means of specific micro- to nano-scale material removal meant to change the wettability of the prosthetic. In order to achieve the desired surface texture, a sufficiently small magnetic abrasive hybrid particle must be used in the MAF process. Current commercial magnetic abrasive particles (80μm mean diameter) are too large to perform this small scale material removal. In this study, the synthesis of a hybrid magnetic abrasive nano-particle for the use in this process is investigated and some promising initial results are presented.

INTRODUCTION

The goal of this project is to produce surfaces with characteristics in the nanometer to micrometer range that enable desired functionality for complex-shaped components. Surface functionalization will be realized using a magnetic field to locally manipulate abrasives, which cause material removal and surface deformation. This magnetic abrasive finishing (MAF) process will be specifically applied to austenitic stainless steels and ultra high molecular weight polyethylene (UHMWPE) due to their immediate relevance to biomedical applications, including knee implants.

This presentation focuses on producing a hybrid nanoparticle consisting of magnetic material and abrasives. One example of such a particle is a core shell nanoparticle.



$Fe_3O_4@SiO_2$

SURFACE FUNCTIONALIZATION BY MAGNETIC ABRASIVE FINISHING

WETTABILITY

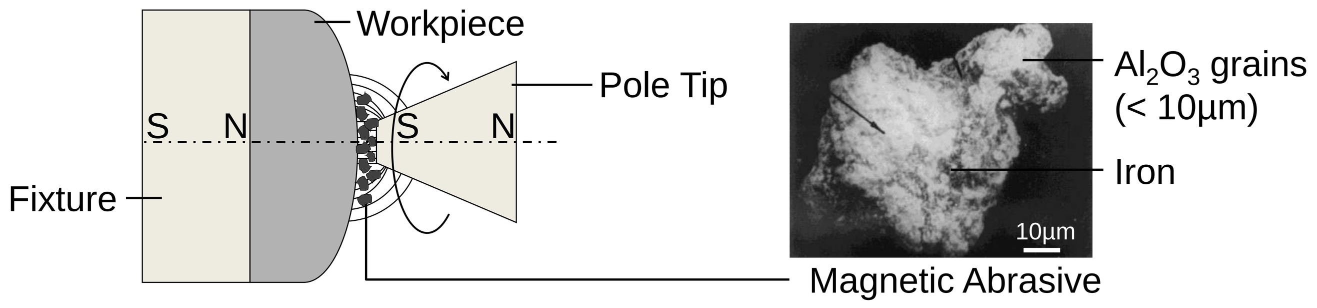
The wettability of a material is the tendency of a liquid to adhere to its surface. One way to gauge wettability is by measuring the contact angle between the given surface and a drop of liquid. When two different materials are placed in contact, a large difference in wettability between their respective surfaces has shown to increase the fluid film thickness between them and therefore improve lubrication. MAF will be used to texture the biomedical components' surfaces in order to improve lubrication and decrease wear in the components.

MAGNETIC ABRASIVE FINISHING

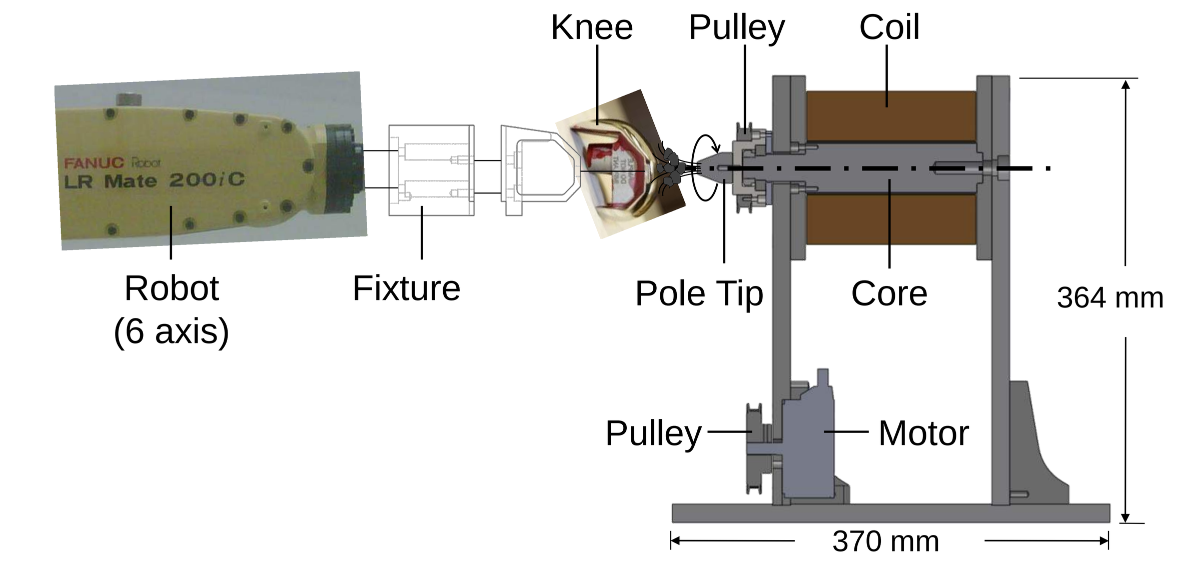
MAF is a finishing process used to remove material from a surface using abrasives or a magnetic abrasive slurry that is manipulated via a magnetic field.

The abrasives/slurry used in MAF must be:

1) Harder than the material being finished
2) Manipulated in a magnetic field (magnetic)
3) Small enough to produce the nano-scale material removal



Schematic of Processing Principle



Experimental Setup

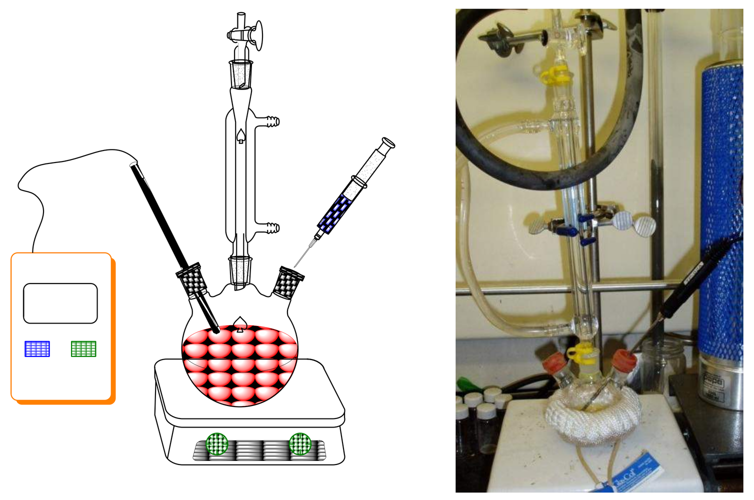
EXISTING MAGNETIC ABRASIVE

Since abrasives are not magnetic, manipulating them in a magnetic field proves challenging. To solve this problem, a composite magnetic abrasive can be made by attaching the abrasive to a magnetic particle via a sintering, thermite, plasma, or similar process. There are an extremely limited number of commercially available versions of this type of composite magnetic abrasive, and all are too large for this application.

NANOPARTICLE SYNTHESIS

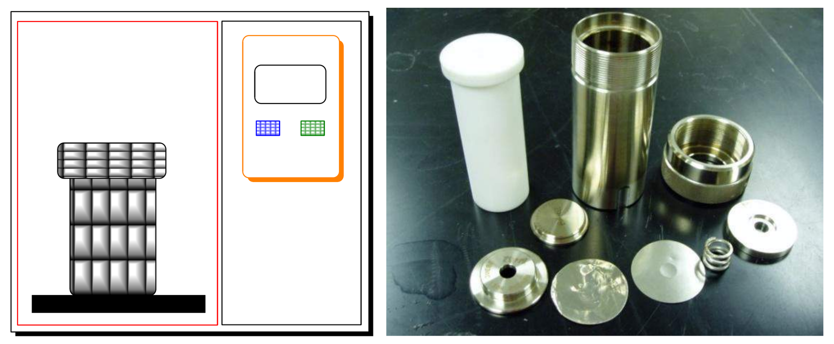
Two synthesis routes were used:

Solution Precipitation is a process by which a precursor is injected into a solution under inert atmosphere at a given temperature. The resulting solution is then refluxed for a given amount of time until it precipitates.



Solution Precipitation

Solvothermal is a process by which all reactants are placed in a sealed stainless steel reaction bomb shown to the right. It is then placed in a furnace at given temperatures for a set amount of time. The combined heat and pressure allow the chemical reaction to take place.

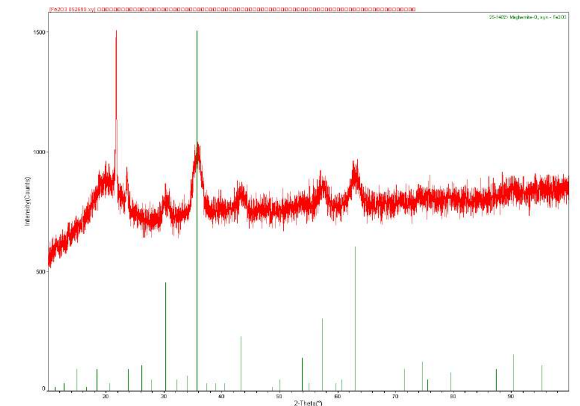


Solvothermal

NANOPARTICLE SYNTHESIS

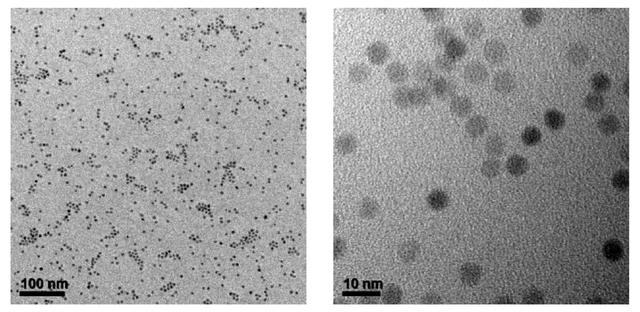
Iron Oxide (Fe_2O_3) dots were synthesized using a solution precipitation route, resulting in particles with a tight mean diameter distribution of 5.5 nm.

$$Fe(CO)_5 \xrightarrow[\Delta 295\ C\ (2h)]{OE/OA} FeO \xrightarrow[\Delta 80\ C\ (18h),\ \Delta 295\ C\ (2h)]{OE/OA/air} Fe_2O_3$$



XRD Results of Fe_2O_3 Dots

Woo, K. et al. "Easy Synthesis and Magnetic Properties of Iron Oxide Nanoparticles."

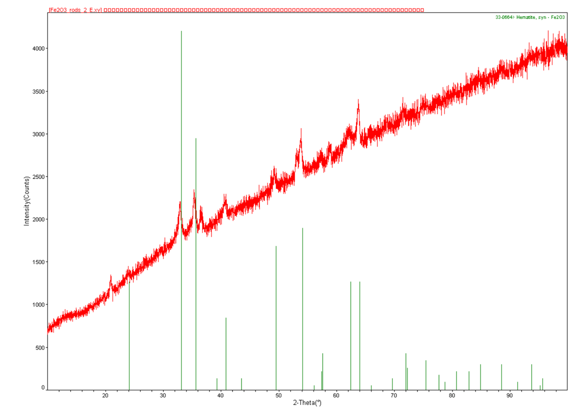


TEM Images of Fe_2O_3 Dots

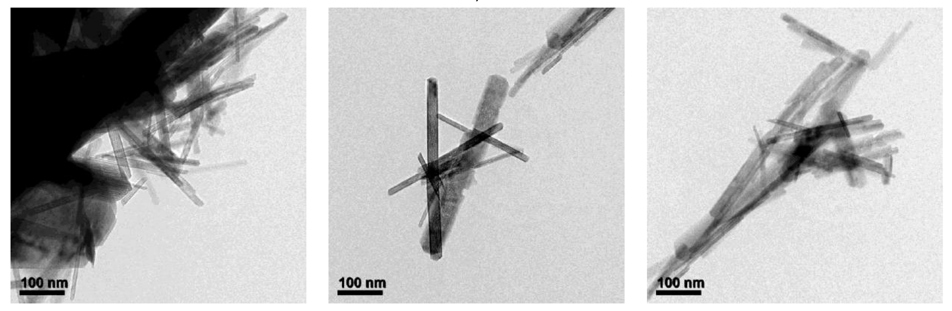
FeOOH and Fe_2O_3 rods were synthesized using either a solvothermal route or simply heating the mixture in air.

$$FeSO_4{\cdot}7H_2O + NaO_2CCH_3 \xrightarrow[8h]{\Delta 100\ C} FeOOH_{(ppt)} + Na_2SO_{4\ (aq)}$$

$$FeOOH \xrightarrow[Air,\ 8h]{\Delta 250\ C} Fe_2O_3$$

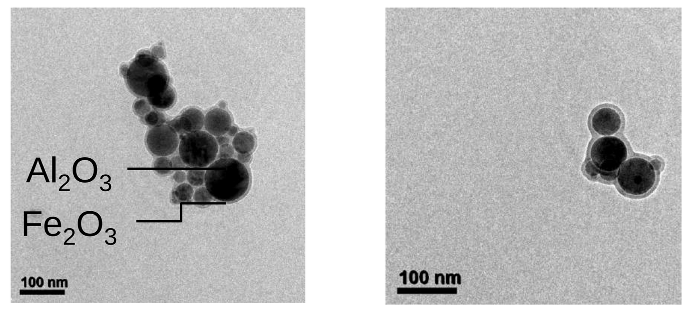


XRD Results of Fe_2O_3 Rods

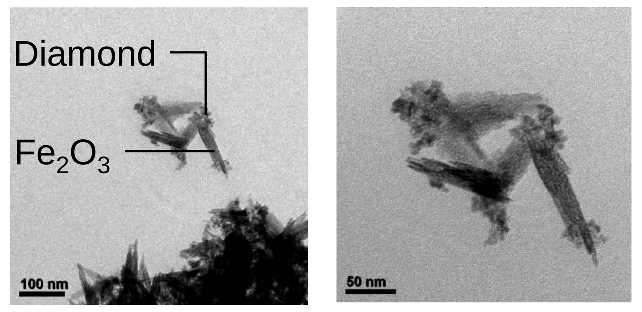


TEM Images of Fe_2O_3 Rods

HYBRID NANOPARTICLE



Aluminum Oxide / Iron Oxide



Diamond / Iron Oxide

CONCLUSIONS

Both spherical (dots) and rod-like magnetic nanoparticles were successfully synthesized. The hybrid magnetic abrasive nanoparticle synthesis is still being optimized. Attempts are being made to decrease agglomeration and create a coreshell particle with iron oxide as the core and an abrasive as the shell. Polishing tests are being carried out to determine the current particle's effectiveness as a magnetic abrasive.

ACKNOWLEDGEMENTS

I would like to thank my mentor at SNL, Dr. Bernadette Hernandez-Sanchez for helping me throughout the project. Additionally, I would like to thank the NSF SNL-NINE program (Award No. 0855381) and Dr. Geoffrey Brennecka, SNL, for their financial support.