Estimation of Fluid Pressure in the Process of Magnetorheological Flow Finishing By Using Comsol Multiphysics 4.4

SARIKA CHOTHE
PRASHANT PAWAR
ANIL SHINDE

DEPARTMENT OF MECHANICAL ENGINEERING
SVERI'S COLLEGE OF ENGINEERING, PANDHARPUR

COMSOL CONFERENCE
2014 BANGALORE

Excerpt from the Proceedings of the 2014 COMSOL Conference in Bangalore

OUTLINE

Introduction

BACKGROUND & MOTIVATION

- Surface finish has a vital influence on important functional properties such as wear resistance and power loss due to friction on most of the engineering components.
- In some applications like lenses and mirrors, surface finish plays a significant role in reflecting or refracting white light, laser, x-ray, or other particle beams.
- In these materials, surface properties are of utmost importance and require control at atomic level.
- Nanofinishing is only operation which can make these surfaces useful for desired applications.

CHEMO-MECHANICAL MAGNETORHEOLOGICAL FINISHING (CMMRF) PROCESS

- Chemo-mechanical Magnetorheological finishing (CMMRF) process is a hybrid nano/subnano finishing process.
- It has been developed by hybridizing Chemical Mechanical Polishing (CMP) and Magneto-rheological Finishing (MRF) processes.
- CMMRF process comprises two aspects of finishing like formation of chemical passivation and magnetically assisted mechanical abrasion.
- This process has capability to develop surface finish of the order of few Angstroms.

CHEMICAL MECHANICAL POLISHING (CMP)

- Chemical mechanical polishing (CMP) is extensively used in IC industry to process metals and non-metals for atomic level of finishing.
- CMP process has the ability to finish silicon wafers using a polishing pad with abrasives and alkaline solutions that can react with the workpiece.
- In CMP, chemical reactions between the slurry and the workpiece are used to enhance the finish quality and the degree of planarization.
- CMP process has capability of high polishing rate with ultra high level of surface finish (0.2 to 0.3nm).
- This process works at two levels viz. chemical reaction for formation of chemical passivation of superficial layer and abrasive under specified processing or polishing parameters.

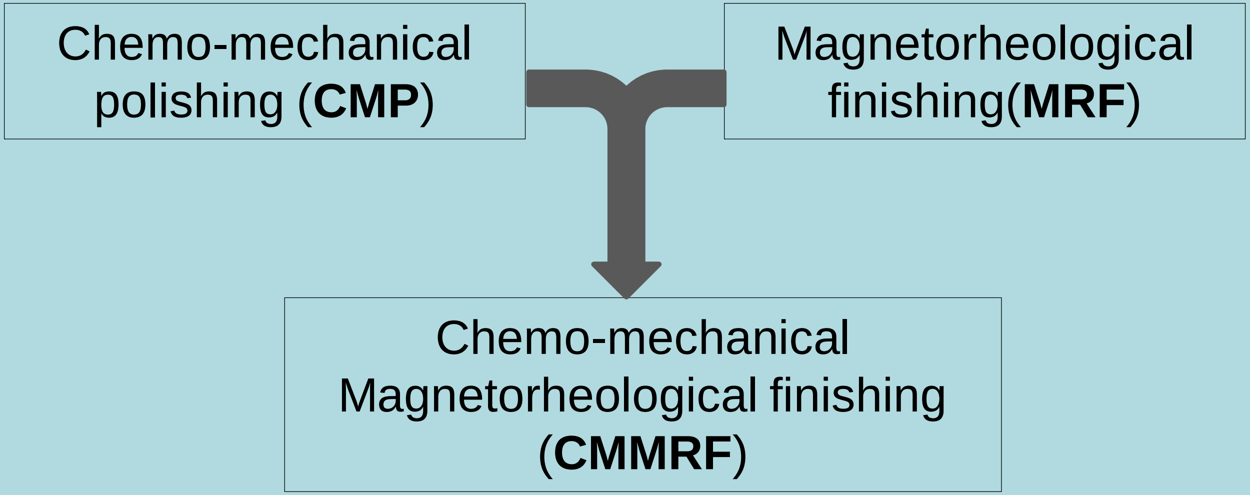
MAGNETO RHEOLOGICAL FINISHING (MRF)

- Other than chemical aspects of CMP, mechanical action of finishing has been introduced from MRF process.
- Concept of Magnetorheological phenomena is taken from MRF process to fabricate Magnetorheological polishing (MRP) pad or flexible brush.
- The MRP pad contains abrasive particles (non-magnetic) in chain of CIP (carbonyl iron particle) under the influence of magnetic field.
- When the pad comes in contact with the workpiece surface, it is squeezed and it applies a force normal to the work surface. The normal force thus adds to the normal component of the magnetic force to increase abrasive penetration into the chemically pasivated layer of the workpiece. The tangential force acting on the abrasive particle due to the combined effect, removes the material from the peaks of the workpiece surface resulting in the formation of CMP

CMMRF

DEVELOPMENT OF CMMRF

Chemo-Mechanical Magnetorheological Finishing (CMMRF)



Chemo-mechanical polishing (**CMP**)

Magnetorheological finishing(**MRF**)

Chemo-mechanical Magnetorheological finishing (**CMMRF**)

CMMRF Development

ADVANTAGES OF CMMRF

Benefit of this process over other Processes

- It uses **magnetic field assisted polishing pad** instead of conventional polishing pad of CMP (**Flexibility of the Process**).
- Continuous **cycling of MR polishing fluid** protect polishing pad characteristics, results **repeatability & Pad life** of the finishing
- The finishing set-up is similar to **MRF process**, hence **flexible polishing pad** removes **shape limitation** on the workpiece surface to be finished.
- The **limitations of MRF** (SSD & low PR) are minimized by hybridizing it with CMP process.
- The **limitations of CMP** (polishing pad & W/P shape) are minimized by hybridizing it with MRF process.
- The surface **roughness** of final finished surface depends on **abrasive** and **magnetic particles size** as well as **magnetic field**. These are the controlling parameters.

Mechanism of Finishing

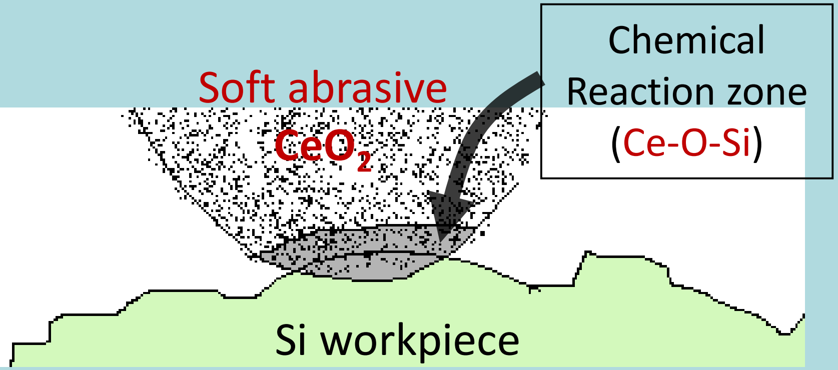
MECHANISM OF FINISHING

The holding force and cutting force of abrasive in CMMRF process can be calculated and controlled in real time with the help of magnetic field and working gap as well, hence helps in deterministically and selectively abrading the workpiece passivating surface

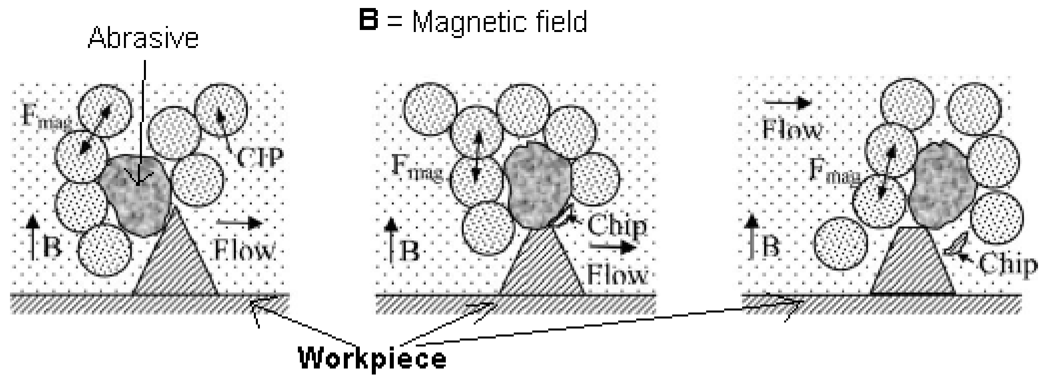
1. Alignment of magnetic particles along magnetic lines of force.
2. Force exerted on magnetic particles depends on magnetic field, size and magnetic properties of the magnetic particles.
3. Entangling of abrasives in between the magnetic particles.
4. Phenomenon of magnetophoresis, gravity, centrifugal force, Coriolis force, viscous force, Van der waal force, etc.
5. It has similar interpretation with lapping process.

MECHANISM OF FINISHING (CONTD.)

- The main function of MRP fluid is to **chemically react** with the Si-substrate to soften it.
- Chemicals in the MR fluid react with surface materials, form chemical compounds that can be **removed by abrasive as well as Magnetic particles**
- In aqueous solution, it forms hydroxyl, that is easily removed by magnetic and / or abrasive particles.
- CeO_2 becomes chemically active and **soft abrasive** to the silicon substrate. It is used for ultra finishing



Chemical Reaction in the Process



Magnetically assisted Mechanical action

MECHANISM OF FINISHING (CONTD.)

Chemical Reaction of workmaterial with MR fluid as well as abrasive, Worksurface becomes soft

↓

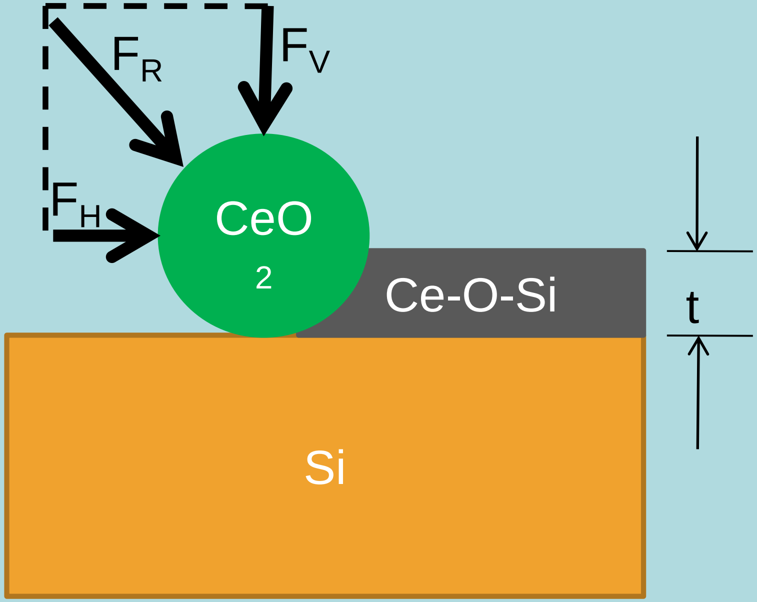
Mechanical erosion with mechanical movement of magnetically stiffened polishing disc

↓

Material removal in the scale of nano level

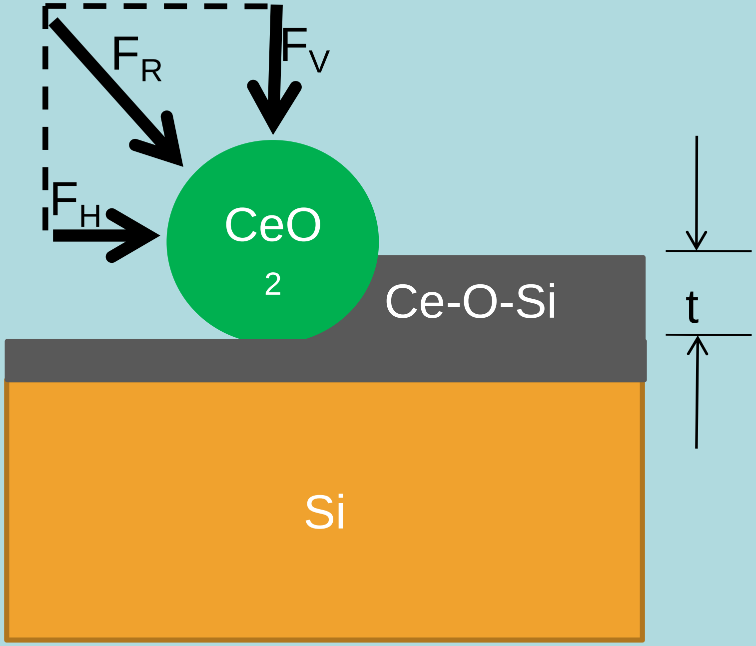
MECHANISM OF FINISHING (CONTD.)

Thickness of passivation layer depends on **Chemical Reaction kinetics, Relative velocity, & Magnetic field.**



1. Thinner layer of passivation for hard w/p

Case1. $\sigma_y (\Pi/4)(2Dt) < F_V$



2. Thicker layer of passivation soft w/p

Case2. $\sigma_y (\Pi/4)(2Dt) = F_V$

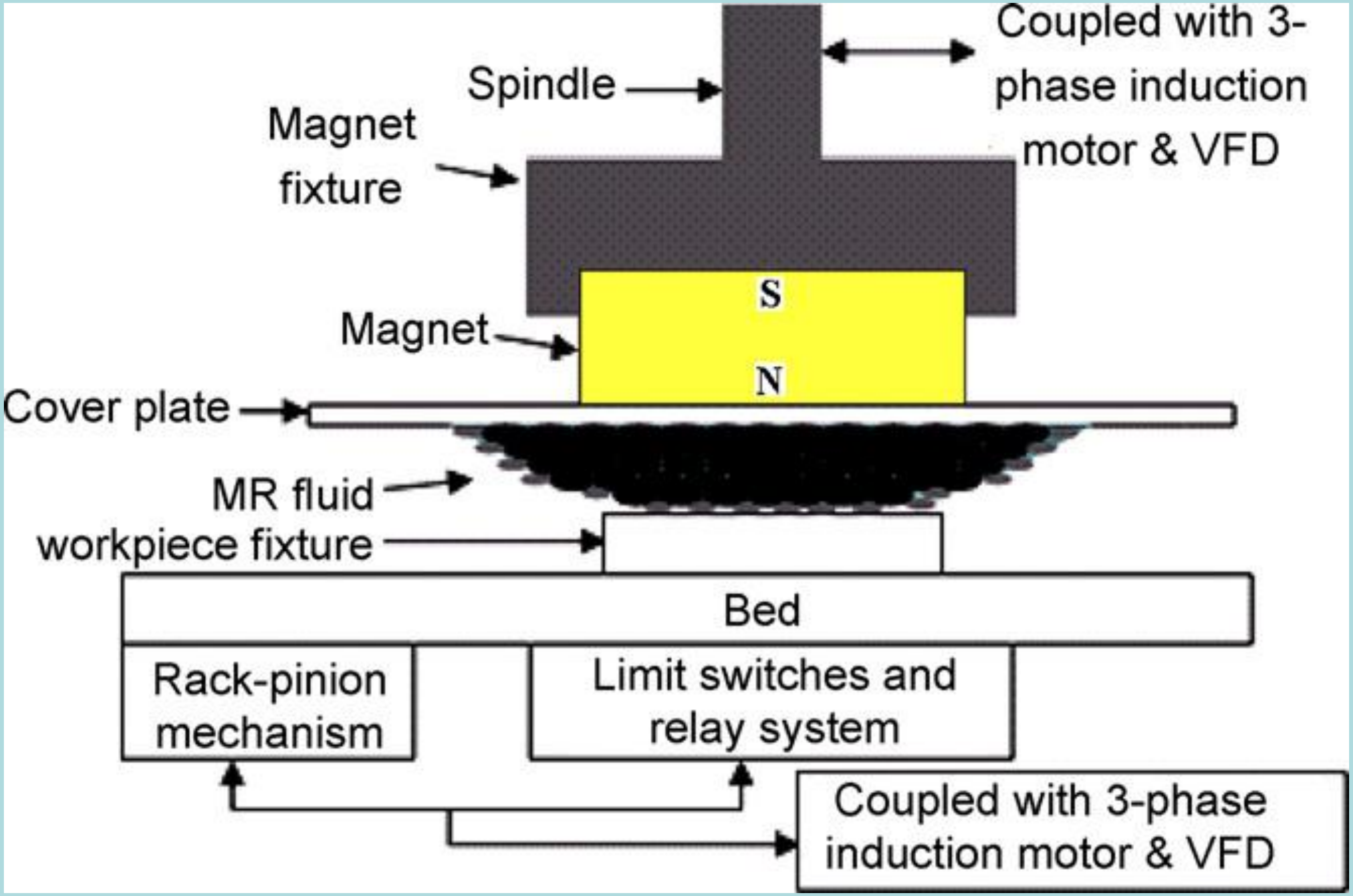
Were, D= Mean diameter of abrasive, σ_y =Yield strength of passivating layer in compression.
F_V, F_H, & F_R =Cutting force, holding force and resultant force generated by magnetism

CMMRF POLISHING FLUID

- MR polishing fluid consists of deionized water (DI), abrasives (SiC, Al_2O_3, or CeO_2) and ferromagnetic particles (Fe).
- To avoid sedimentation of ferromagnetic and abrasive particles, glycerol (soluble in water) was added. Either iron particles or carbonyl iron particles (CIPs) are used as ferromagnetic particles.
- DI water as base material is chemically active on the (Si) work surface.
- Two types of MR polishing fluid are prepared, one with single type of abrasive (CeO_2) and another with two types of abrasives CeO_2 and SiC (or Al_2O_3). The first one is softer than the second one.

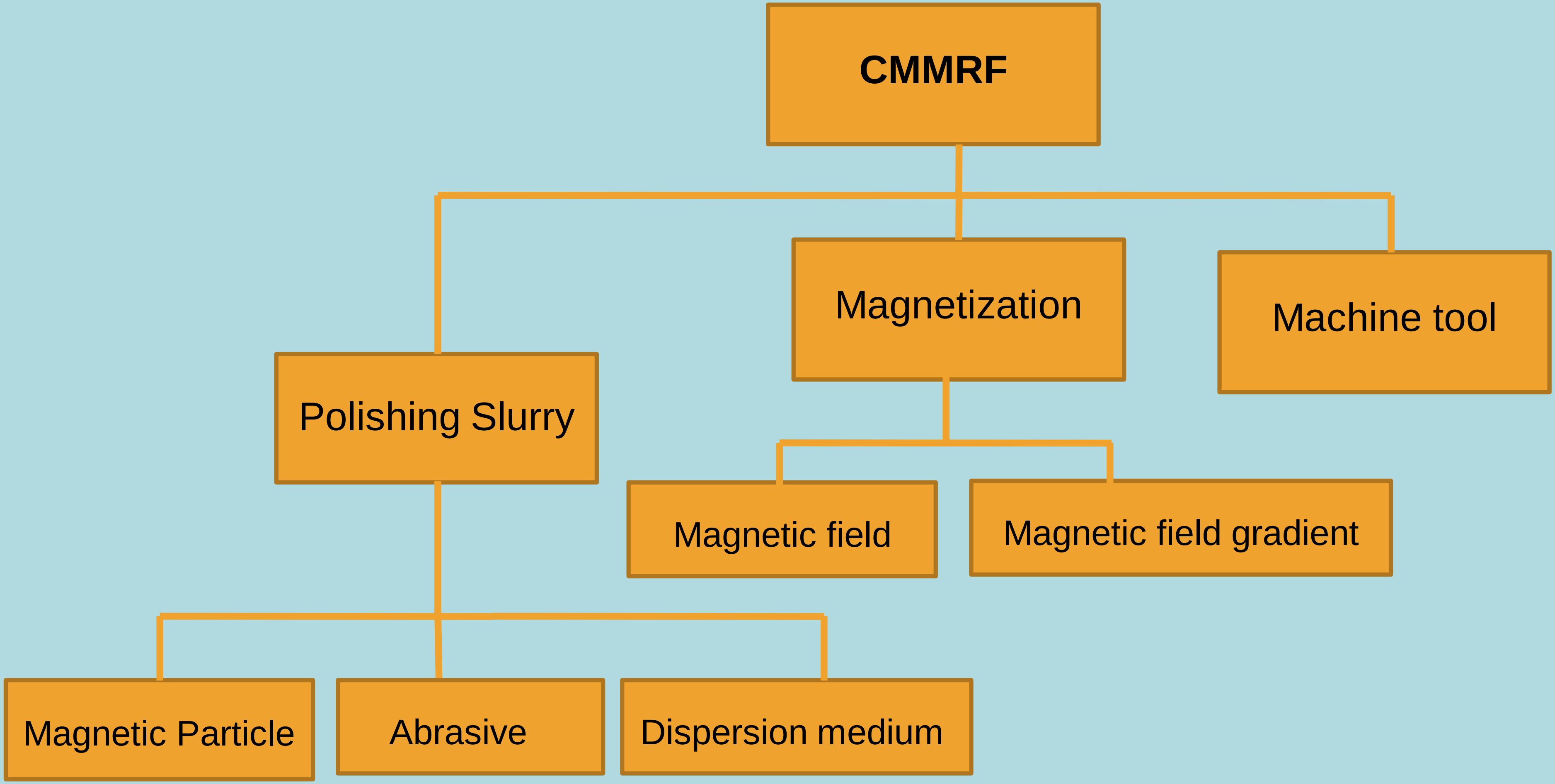
CMMRF SET-UP

Schematic



CMMRF

Important aspects



CMMRF

Polishing Slurry

Magnetization

Machine tool

Magnetic field

Magnetic field gradient

Magnetic Particle

Abrasive

Dispersion medium

Process Parameter

PROCESS PARAMETERS

- **MR fluid**
    1. Composition
    2. Size of Magnetic particles
    3. Size of abrasive particles
    4. Viscosity of the fluid
- Magnetic field in working zone
- **Working gap**
- **Rotational speed to the magnet**
- **Feed to the workpiece**
- **Finishing time**

Use of COMSOL

USE OF COMSOL

- **Specification of problem**

Swirl flow is an unusual application that involves steady rotational flow around an axis. Rather than modeling this process in 3D, the CFD Module provides a 2D axisymmetric physics interface where the flow in the rotational direction is still included in the equations. This example shows the effect of a rotating cylinder on the flow in a container as shown in figure. The diameter, thickness of rotating disc is 5mm, 0.5mm respectively. The working gap between the fluid and workpiece is 0.4mm. The angular velocity is taken as 100rpm, 200rpm and 300rpm.Such applications are often used in chemical kinetic experimental devices known as rotating disk electrodes.

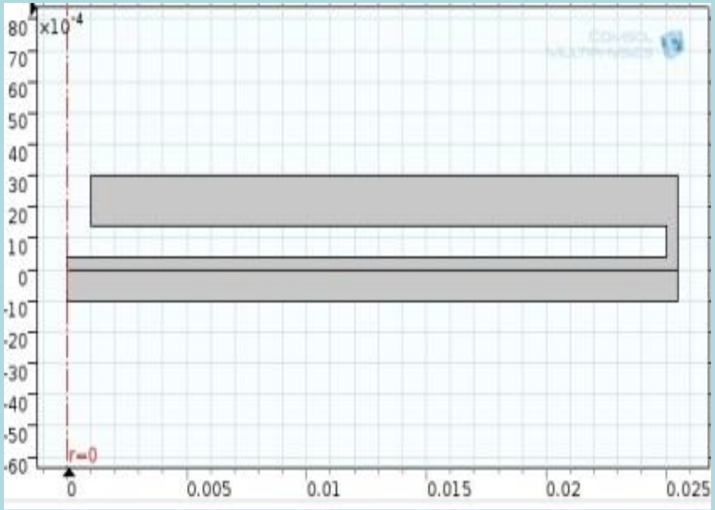


Figure: Geometry of rotating disk

Excerpt from the Proceedings of the 2014 COMSOL Conference in Bangalore

USE OF COMSOL (CONT…)

- **Material Property**

MR fluid is used as working fluid. The dynamic viscosity of water is 60Pa-sec.

- **Boundary Condition**

A no slip boundary condition was assigned for the fluid at the wall surfaces, where velocity is set to zero.

USE OF COMSOL (CONT…)

- **Meshing of Geometry**

Structured meshing method is used for meshing the geometry in Comsol Multyphysics. The 3D geometry of rotating disc with coarse mesh is as shown in figure.

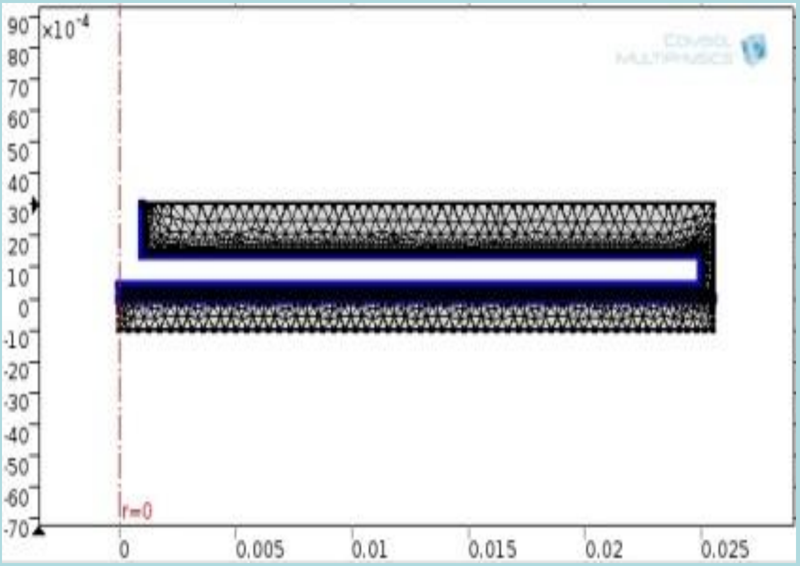


Figure: Two dimensional geometry of rotating disk with coarse mesh

Result & Discussion

RESULTS

The various results are obtained for rotating disc for different parameters as follows. The Comsol Multiphysics is used for obtaining flow and stress pattern of rotating disc. The rotating spindle speed is used in this analysis is optimizes speed based upon the experimental work. The speed is 100rpm, 200rpm and 300rpm.

Case I

Spindle Speed = 100RPM

Working gap = 0.4mm

Viscosity = 60Pa-s

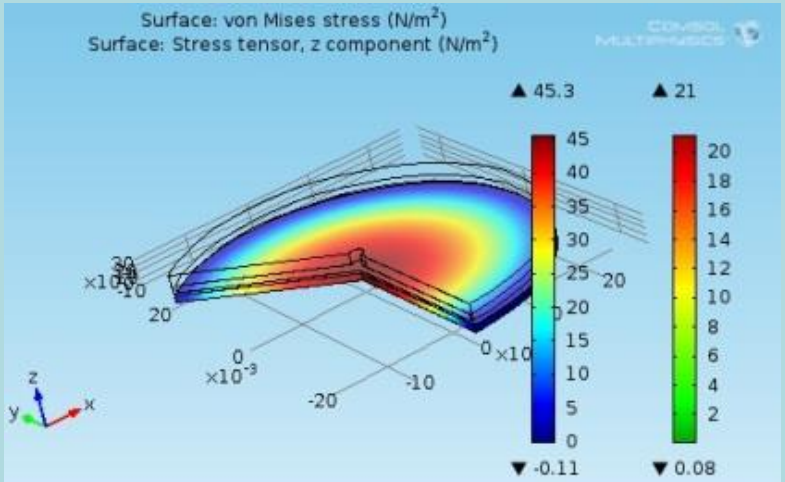


Figure: Stress tensor

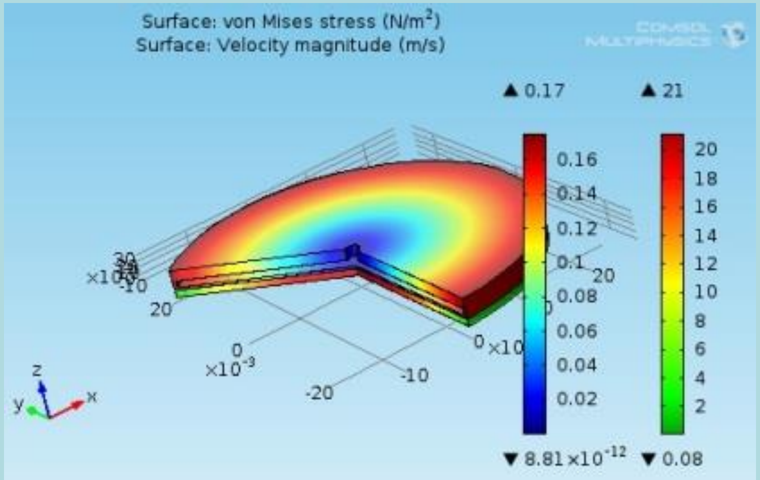


Figure: Von-misses stress

RESULTS (CONT…)

Case II

Spindle Speed = 200RPM

Working gap = 0.4mm

Viscosity = 60Pa-s

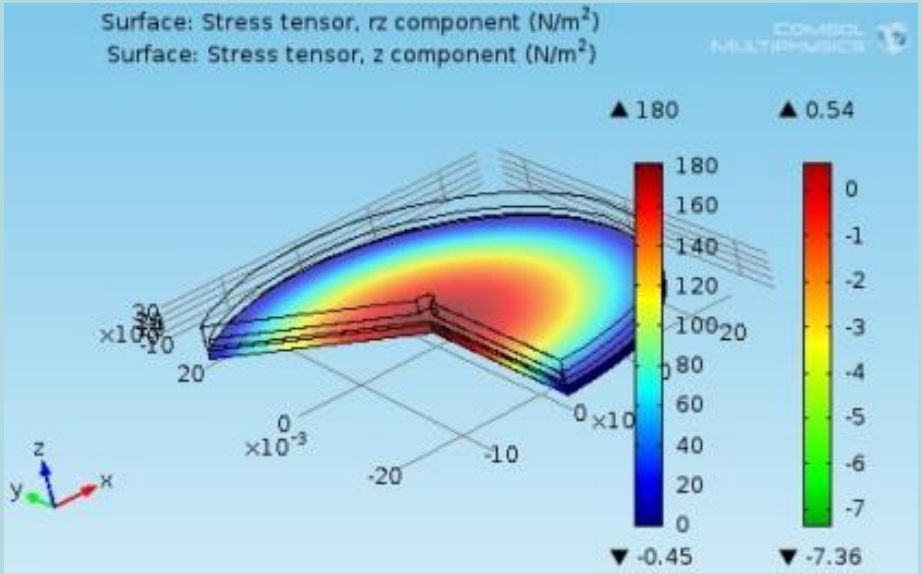


Figure: Stress tensor

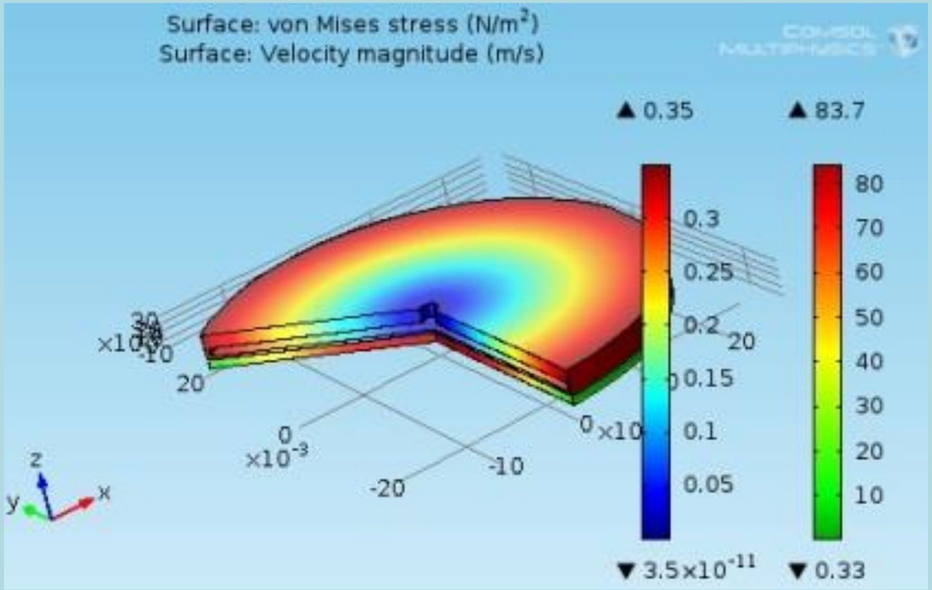


Figure: Von-misses stress

RESULT (CONT…)

Case III

Spindle Speed = 300RPM

Working gap = 0.4mm

Viscosity = 60Pa-s

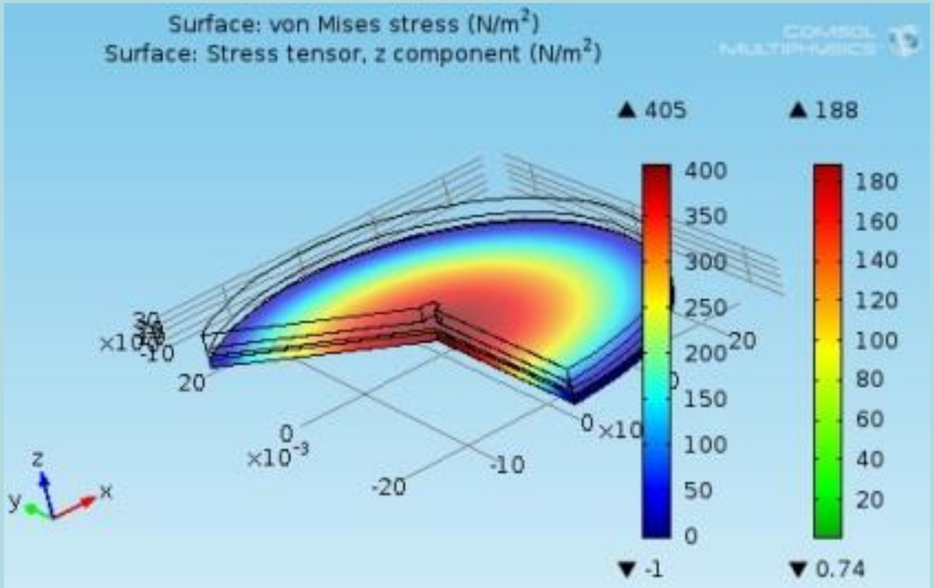

Surface: von Mises stress (N/m^2)
Surface: Stress tensor, z component (N/m^2)

Figure: Stress tensor

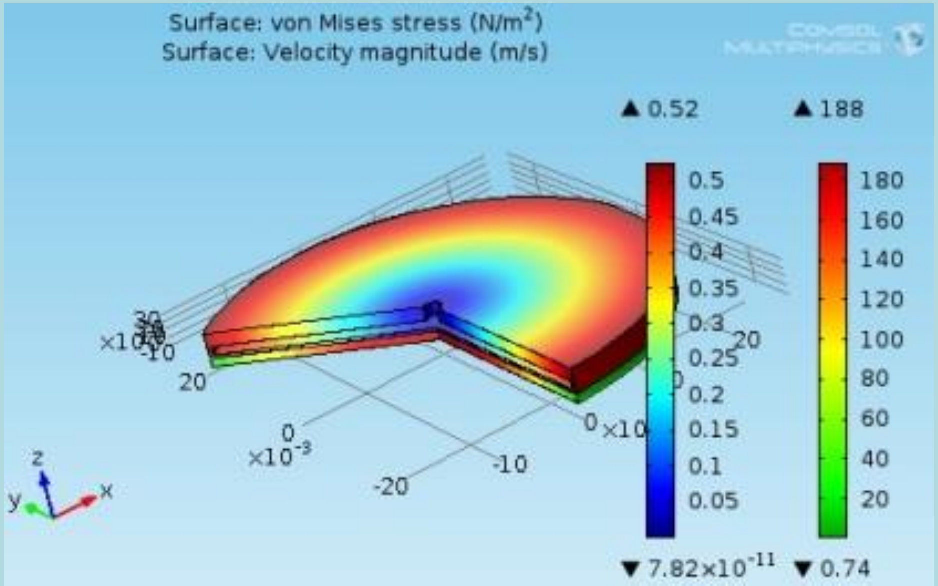

Surface: von Mises stress (N/m^2)
Surface: Velocity magnitude (m/s)

Figure: Von-misses stress

RESULT (AFM SURFACE)

Sr. No.	Parameters	Stress tensor (N/m^2)	Von-misses stress (N/m^2)	Velocity (m/s)
1	Spindle Speed = 100RPM Working gap = 0.4mm Viscosity = 60Pa-s	45.3	21	0.17
2	Spindle Speed = 200RPM Working gap = 0.4mm Viscosity = 60Pa-s	180	83.7	0.35
3	Spindle Speed = 300RPM Working gap = 0.4mm Viscosity = 60Pa-s	405	188	0.52

Conclusion

CONCLUSION

- In this paper behavior of pressure distribution is studied as per requirement.
- COMSOL MULTIPHYSICS4.4 process has been used to obtain flow and stress distribution in rotating disc.
- The effects of different spindle speed on velocity change and stress distribution of rotating disc.
- As speed is increasing stress tensor, von-mosses stress and velocity is increasing and vice a versa.

THANK YOU