Development of an Experimental Set-up for producing Metal and Ceramic Functionally Graded Materials

A Thesis Submitted for Partial Fulfilment
of the Requirements for the degree of

Bachelor of Technology
in

Mechanical Engineering
by

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National Institute Of Technology Rourkela
Rourkela-769008
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Under the Supervision Of
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National Institute of Technology, Rourkela

CERTIFICATE

This is to certify that the work in the thesis entitled “Development of an Experimental Set-up for Metal and Ceramic Functionally Graded Material” by Sourav Bikash Satapathy, has been conducted under my supervision required for partial fulfillment of the requirements for the degree of Bachelor of Technology in Mechanical Engineering during session 2014-2015 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela.

To the best of my knowledge, this work has not been submitted to any other University/Institute for the award of any degree or diploma.

Dr. Subrata Kumar Panda
(Supervisor)
Assistant Professor
Department of Mechanical Engineering

ACKNOWLDEGMENT

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ABSTRACT

Functionally graded materials are a class of advanced composites with graded properties that bring a new concept in material design and are widely used in the aerospace and automotive industry. These materials have continuously varying microstructure and properties. They are known to have little residual and thermal stress. This concept imparts improved adhesive bonding strength between metals and ceramics. Multifunctional metal-ceramic structures are well suited for applications where toughness and hardness are two essential requirements. Metal-ceramic functionally graded materials can also be designed to take advantage of the mechanical strength of metals and corrosion resistance properties of ceramics in applications such as thermal or chemical barriers. In the fabrication of these materials, powder processing begins with pure Nickel and Alumina powder along with titanium oxide as a sintering aid. The amount of powder required is automated using Arduino. Then it is blended in a mixing chamber after passing through a nozzle. Quick return mechanism is used to spray blended powder into mould layers. The powdered layers are compacted. The compacted material is sent to the sintering chamber and sintered for required duration. The specimen is subjected to different mechanical tests, and analytical results are compared with experimental results.

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List of Symbols

Symbols	Description
S_1	Length of fixed link
S_2	Length of crank
S_3	Position of slider in slot from pivot point
S_4	Length of coupler
S_5	Length of connection link
S_6	Horizontal position of slider from pivot point
S_7	Vertical position of slider from pivot point
V_6	Velocity of slider
ω_4	Angular velocity of coupler
A_6	Acceleration of slider
α_4	Angular acceleration of coupler
α_5	Angular acceleration of connecting link

Chapter 1

Introduction

1.1 Background

Laminated composites have received a lot of interest in recent days by diversified and potential applications in many applications like aerospace and automotive industry due to their elevated strength to weight, stiffness to weight ratio, low fatigue life and toughness and other higher material properties. These are made from two or more materials which have different chemical or physical attributes and produced a material having different behavior from the individual. These are used in several applications like buildings, bridges etc. Each layer is graded in order to get superior material properties. The individual layer has high strength fibers like graphite, glass or silicon carbide and matrix materials like polyimides, epoxies etc. By varying the thickness of laminas desired properties (strength, wear resistance, stiffness) can be achieved.

Although these materials have superior properties, their major drawback is the weakness of laminated layers. This is delamination phenomenon which leads to the failure of the composite structure. Residual stresses arise due to difference in thermal expansion coefficient of the constituent matrix and fibre. It is common that at high temperature the adhesive being chemically unstable and fails to hold the lamination. Sometimes due to fibre breakdown it also prematurely fails. Functionally Graded Material (FGM) is combination of a ceramic and a metal. A material in which its structure and composition both varies gradually over volume in order to get certain specific properties of the material hence can perform specific functions. The properties of graded materials depend on the spatial position in the structure of material. The effect of inter-laminar stress developed at the laminated composite interfaces due to sudden change of material properties reduced by continuous grading of material properties. Generally microstructural heterogeneity or non-uniformity is introduced in functionally graded material. The main purpose is to increase fracture toughness, increase in strength because ceramics exhibit brittle material properties. Brittleness is a great drawback for any structural application. These are produced by blending both metals and ceramics for use in high temperature applications.

Material properties are varying in one or many directions, so FGMs are inhomogeneous. FGM serves as a thermal barrier that is capable to withstand 2000K surface temperature. Different fabrication methods of producing FGMs involve layer processing, melt processing, bulk processing, particulate processing etc. FGM has the ability to control corrosion, wear, buckling, deformation etc. and also to remove stress concentrations. This can be used at high temperature applications as in microelectronics as thermal shielding element and spacecraft, hypersonic and supersonic planes and in combustion chamber as thermal protection systems.

1.2 Fundamental concepts about FGMs

The properties of ceramics or metals are a showcase of their adhesive bonding nature, such as bonding length and strength. Ceramics regularly exhibit properties like high hardness, low density, brittleness, refractoriness, creep, corrosion resistance, radiation, wear and thermal shock resistance. On the other hand, metals are normally ductile, high tensile strength, high toughness and density.

Multifunctional metal-ceramic structures are well suited for applications where both toughness and hardness are desired. One example is a gear, which satisfies different functional requirements for the teeth and body. The teeth of the gear must be hard and wear resistant to contact forces, whereas the gear body must be tough enough to withstand fracture. Similarly, armor requires a hard outer surface and tough inner surface, as seen in Figure 1.1. Upon projectile impact, the hard outer surface restricts a shock wave on the projectile and the tough inner surface absorbs the residual kinetic energy from the projectile. However, conventionally bonded metal-ceramic plates have the disadvantage of a weak interface that affects propagation of stress wave. Thus, a compositional gradient that removes the sharp interface between materials is ideal for an armor package. The delay time to cause damage in the FGMs has greater dynamic energy absorbing capacity than a non-graded bonded structure.

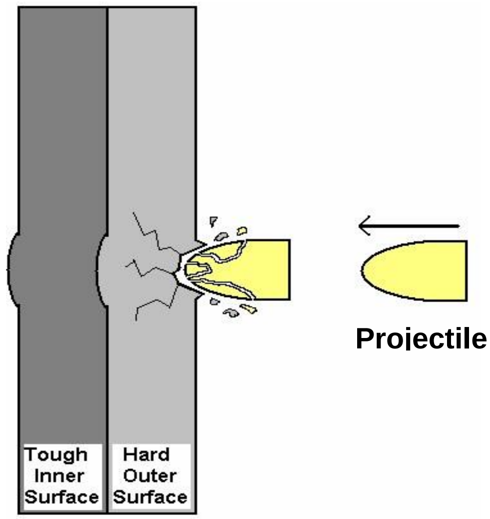


Figure 1.1: Ceramic-metal armor plating

Moreover other application involves development of graded metal-ceramic gun barrels. A ceramic inner barrel liner with a metal-based jacket allows for the use of higher energy propellants to produce more energy to the target. Metal-ceramic FGMs can also be designed to use the ceramic advantages like heat and corrosion resistance and metal advantages like the mechanical strength to be used as thermal or chemical barriers.

The introduction of a material gradient structure to reduce a sharp interface presents new fabrication challenges for experimental set up. In order to simplify the fabrication techniques, this continuous transition in microstructure is often viewed by discrete layers of distinct composite compositions, as seen in Figure 1.2. Properties of these composite compositions are often studied and then represented by rule-of-mixtures or modified ROM formulations. However, the introduction of the material gradient to replace the sharp interface does not eliminate the formation of stresses due to the different material properties of both the materials but under certain conditions may result in higher local stress concentrations. As a result, gradients must be carefully designed to reduce the formation of these stresses. There are several ways to tailor the graded microstructure, a popular one being a power law model discussed in the following sections.

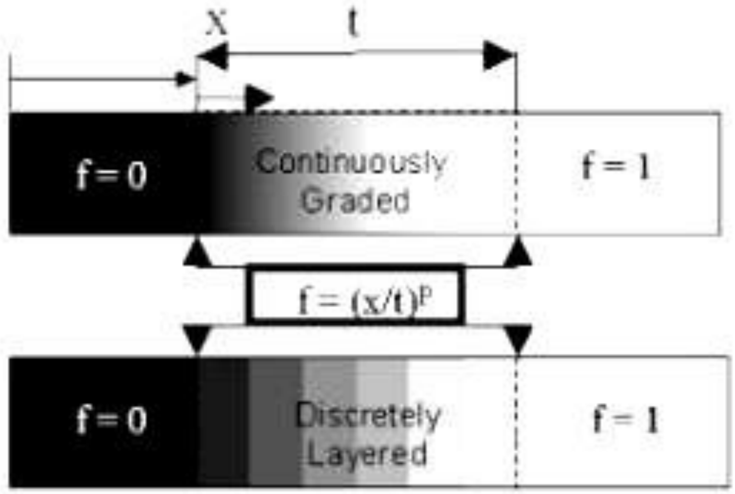


Figure 1.2: Continuously graded structure and corresponding approximation using discrete layers

1.3 Residual Stresses Associated With FGMs

Due to the discontinuity occurring in properties at the sharp interface, thermal and mechanical loading on a multi-material structure generates residual stresses. In general, failure mode is observed in bonded metal-ceramic structural components as tensile edge stresses within the ceramic promote crack propagation parallel and adjacent to the interface. The theory of stresses produced by thermal loading for a bonded metal-ceramic is shown in Figure 1.3.

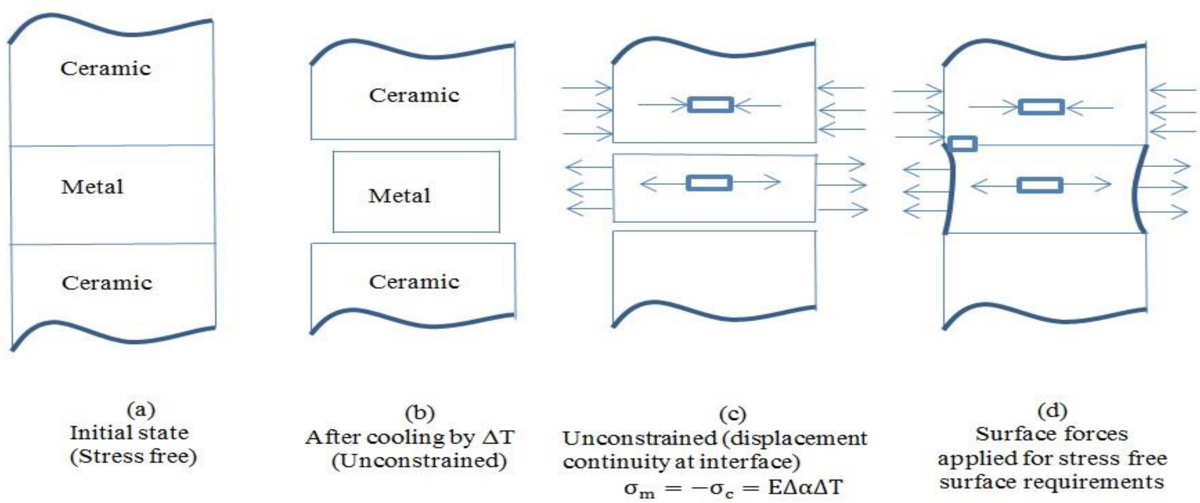


Figure 1.3: Conditions of a bonded metal-ceramic composite when introduced to thermal loading

Elimination of the sharp interface by the use of gradation law between is highly essential. However, residual stresses still continue to develop at the new heterogeneous interfaces introduced by the compositional gradient of multi materials. The consolidation process typically introduces significant thermal loads on the FGMs structure during cooling from the processing temperature. The response to thermal loads of each microstructural composition in the structure is unique. As a result, stresses develop in the structure and due to different cooing rates and gradient consolidation. The generated residual stresses lead to fracture of the FGM structure during fabrication. Finally, compositional gradients can be used to reduce metal-ceramic interfacial stresses, but the success of this approach requires knowledge of failure criteria.

1.4 Fabrication Techniques

Several fabrications methods were developed for functionally graded materials which act as a thermal barrier of a in some applications. Some of the methods are powder metallurgy, plasma spraying, physical and chemical vapor deposition, self-propagating high temperature synthesis (SHS) and galvanic forming. The processing of FGMs has been classified in several ways by many researchers. Miyamoto et.al.(1999) classified the fabrication of FGMs into four categories including bulk, layer, perform and melt processing.

Bulk FGMs are the ones that have large volume of material. Bulk processing involves creation of a bulk material having gradational properties. Here the principle of gradation is difference in densities. The process involves stacking of powder and fibers and then stack consolidation. Layer processing involves layering of material by mechanical deposition. It is done by thermal spraying. Deposition of atoms or molecules can be done to achieve this. It can involve physical deposition or chemical vapour deposition. Preform processing is done to modify the existing gradients in the material by the use of graded fields. This method can involve vapour phase diffusion. Melt processing constitutes constructive processing and that associated with mass transfer. It involves gradual phase separation processes.

1.5 Applications of FGM

Due to advanced properties of the FGMs, they are gaining interest in many industries such as:

I. ***Engineering Application***

a. Shafts

b. Engine parts

c. Blades of turbine

ii. ***Aerospace Engineering***

a. Rocket engine components

b. Aerospace parts and skins

iii. ***Electronics***

a. Sensor

b. Actuator

c. Integrated chips

d. Semiconductor

iv. ***Biomaterials***

a. Artificial bones

b. Drug delivery system

Chapter 2
Literature Review

2.1 Literature Review

The functionally graded materials are one of the revolutionary materials which got attention by researchers and various studies have shown the interest in this material. Various research had been conducted and different fabrication processes have been used for the analysis of different properties of functionally graded materials. The functionally graded materials are developed and analyzed using different methods in past and few of the studies are presented here for the sake of brevity.

Ehsan Bafekrpour *et al*. [1] studied the functionally graded synthetic graphite and phenolic nanocomposites and used powder stacking and compression molding techniques to fabricated the same. They fabricated functionally graded nanocomposites with four different gradient patterns of the microstructure of the same geometry and graphite content as well as an experiment conducted for non-graded nanocomposites. Gang Jin *et al*. [2] used powder metallurgy process to developed Mullite/Mo functionally graded material which had a gradual stepwise variation. Thermal shock test also conducted and measured thermo-mechanical resistance of the mullite/Mo system which was better than monolithic mullite. Alibeigloo [3] studied functionally graded carbon nanotube reinforced composite (FG-CNTRC) plate and investigated their bending behavior by embedding in thin piezoelectric layers and applying mechanical load uniformly using simply supported boundary conditions. Several parameters like volume fraction, piezoelectric layer thickness, aspect ratio and modes number have effects on the static behavior of the hybrid plate and it is analysed based on the three dimensional theory of elasticity. Jin and Li [4] developed algorithms for adaptive rapid prototyping/manufacturing (RP/M) which is used for functionally graded material (FGM)-based on the biomedical models. Tool path algorithms are used to produce the contours of the sliced layer. J. Gandra *et al.* [5] proposed to produce aluminum based functionally graded metal matrix composites that were reinforced by SiC ceramic particles. Various methods were required for reinforcement was investigated. They studied a square shaped channel packed with strengthening particles of SiC & concluded it to be more effective when the channel was placed under the probe. Their research focused on effects of tool geometry, speed and rotation. Mahmoud M. Nemat-Alla *et al*. [6] manufactured & investigated aluminum/steel functionally graded materials by powder metallurgy process. Taking different fabrication conditions, different samples were investigated. Bhattacharyya *et al*. [7] designed synthesized and characterized two-multilayered functionally graded materials (FGMs) that are aluminium–silicon carbide (Al/SiC) and nickel–alumina (Ni/Al2O3). Bulk properties like flexural strength, thermal shock were investigated for FGM characterization. Apart from microstructural studies, they also studied the effect porosity content, micro hardness, effective flexural weakness, thermal fatigue behavior and thermal shock resistance. Markworth *et al*. [8] reviewed models for design and performance of functionally graded materials. They suggested some powerful techniques such as fracture analysis, neural network, and percolation theory. Rabin and Williamson [9] focused on the residual stress developing at the interface. Numerical model for elastic and plastic fem was formulated. Potential residual stress reduction methods were investigated. Winter *et al*. [10] fabricated nicked alumina composites using thermal behavior process that minimizes induced stresses. Compaction behavior, shrinkage and sintering rate were analyzed and methods to reduce stresses were discussed. Watanabe [11] investigated the various methods of powder processing and identified the problems in different processed. Various process innovations were featured to impart versatility to the methods. Kruft [12] focused on the pressureless methods so as to develop functionally graded materials. He proposed functionally graded materials based on thermal-elastic viscoplastic constitutive model. Graded ceramic composites were fabricated using bulk molding technology which was further subjected to vibration and microstructural analysis. The study also involved application of nanoparticle sintering aid and analysis of effects. A prototype of commercial bulk molding technology was developed to analyze the effect of processing conditions.

2.2 Aim and Scope of Present Work

The objective of this work is to design & fabricate an experimental set up for metal-ceramic bonded functionally graded material based on powder metallurgy with sintering aid. The goal is to develop a laboratory scale molding assembly similar to assembly developed for concrete industry with some new innovative idea and technology. This research advances the understanding of the processing of graded metal-ceramic composites, a field that has been limited to expensive and complex manufacturing techniques. Main emphasis will be placed on a simple powder blending and to automate the system to avoid complicated powder doping process. Microstructural analysis, stress analysis, vibrational analysis and characteristic properties of FGMs are documented and to model using ANSYS software.

In this study the mathematical formulations of the slotted lever mechanism; the position equations, velocity equations and accelerations are presented in chapter 3. The details of the methodology adopted for fabrication of the setup is presented in chapter 4. The design details of the components and subsystems such as the slotted lever mechanism and power flow systems are presented in chapter 5. Lastly the ansys analysis of nozzle system and the matlab analysis of the crank and slotted lever mechanism were discussed in chapter 6.

Chapter 3

Mathematical Formulation

3.1 Crank and Slotted Lever Mechanism

Crank and slotted lever mechanism is the basic mechanism used to provide higher velocity to output slider during functional time and lower speed during idle time. In this study it is used to spread metal-ceramic powders on the design mould. This mechanism is generally used in slotting machines, shaping machines and in case of internal combustion engines. In this mechanism, the link 3 is fixed which forms the turning pair as shown in figure 3.1. The driving crank (driven by a motor) CB revolves about fixed center C with uniform angular speed. A sliding plate is connected to the crank at (B) which slides under the slotted bar AP. This results in AP oscillating about the pivot point A. A link PR which transmits the motion from AP to the slider which carries the mould and reciprocates along the line of stroke R1R2, is perpendicular to AC to which a slider along with mould is attached. In the extreme position, AP1 and AP2 align tangentially to the circle. The forward stroke (functioning stroke) occurs when the crank rotates clock wise from the position CB1 to CB2 and the return stroke is produced when crank rotates counter clockwise from the position CB2 to CB1.

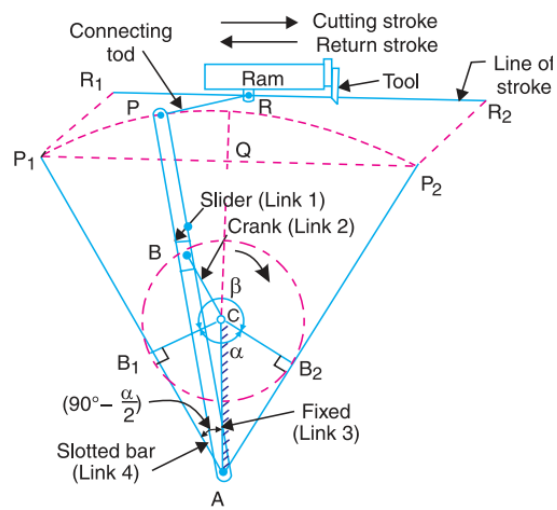


Figure: 3.1: Crank and slotted lever mechanism

For the position analysis of crank and slotted lever mechanism the figure is shown in fig 3.2.

In the mechanism crank S_2 rotates around O_2 360^o. This rotation can be imparted by a DC motor.

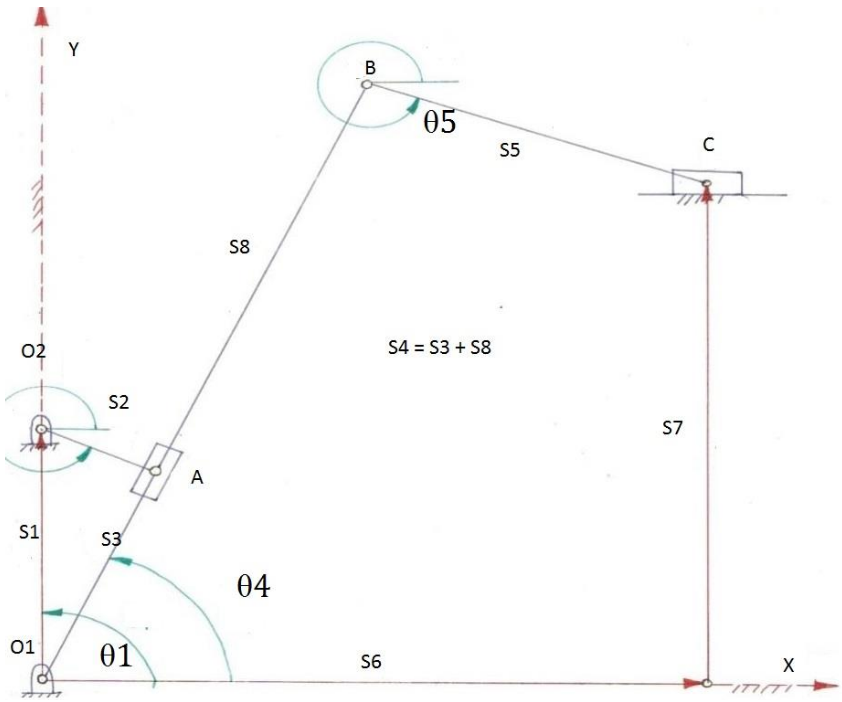


Figure 3.2: Position of different links

3.2 Position Analysis

In order to find different positions of slider at C as a function of input angular position of the crank, complex algebra is used.

Using loop closer equations,

$S_1 + S_2 = S_3$ (1)

$S_3 + S_8 + S_5 = S_6 + S_7$ (2)

Using complex notations equations 1 and 2 can be written as

$S_1e^{i\theta 1} + S_2e^{i\theta 2} = S_3e^{i\theta 3}$ (3)

$S_3e^{i\theta 3} + S_8e^{i\theta 8} + S_5e^{i\theta 5} = S_6e^{i\theta 6} + S_7e^{i\theta 7}$ (4)

Here from the above figure it can be concluded that

$\theta_8 = \theta_3 = \theta_4$ and $S_4 + S_3 = S_8$

Substituting in equations 1 and 2 we get

$$S_3 e^{i\theta 4} = S_1 e^{i\theta 1} + S_2 e^{i\theta 2} \tag{5}$$

$$S_4 e^{i\theta 4} + S_5 e^{i\theta 5} + S_6 e^{i\theta 6} = S_7 e^{i\theta 7} \tag{6}$$

Using Euler equations and separating the real and imaginary parts, the above equations can be depicted as follows:

$$S_3 \cos \theta_4 = S_1 \cos \theta_1 + S_2 \cos \theta_2 \tag{7}$$

And

$$S_3 \sin \theta_4 = S_1 \sin \theta_1 + S_2 \sin \theta_2 \tag{8}$$

Squaring and adding equations 7 and 8

$$S_3 = \sqrt{(S_1 \cos \theta_1 + S_2 \cos \theta_2)^2 + (S_1 \sin \theta_1 + S_2 \sin \theta_2)^2} \tag{9}$$

$$\theta_4 = \tan^{-1}\left(\frac{S_1 \sin \theta_1 + S_2 \sin \theta_2}{S_1 \cos \theta_1 + S_2 \cos \theta_2}\right) \tag{10}$$

Calculating the value of θ_4 , unknown values in equation (6) reduces to 2

$$S_6 e^{i\theta 6} - S_5 e^{i\theta 5} = S_4 e^{i\theta 4} - S_7 e^{i\theta 7} \tag{11}$$

Let $S_4 e^{i\theta 4} - S_7 e^{i\theta 7} = Se^{i\theta}$

Substituting in equation (11) and breaking the equation into real and imaginary parts

$$S_6 \cos \theta_6 - S_5 \cos \theta_5 = S \cos \theta \tag{12}$$

$$S_6 \sin \theta_6 - S_5 \sin \theta_5 = S \sin \theta \tag{13}$$

Solving equations (12) and (13),

$$S_6 = \left(\frac{S \cos \theta + S_5 \cos \theta_5}{\cos \theta_6}\right) \tag{14}$$

And

$$S_6 = \left(\frac{S \sin \theta + S_5 \sin \theta_5}{\sin \theta_6}\right) \tag{15}$$

Equation (14) is used when $\cos \theta_6 > 0$ and equation (15) is used $\cos \theta_6 = 0$

Substituting equation (14) in (13)

And solving for θ_5,

$$\theta_{5a} = \theta_6 + \sin^{-1}\left(\frac{\mathrm{S}\cos\theta\sin\theta_6 - \mathrm{S}\sin\theta\cos\theta_6}{\mathrm{S}_5}\right) \tag{16}$$

$$\theta_{5b} = \theta_6 + \pi + \sin^{-1}\left(\frac{\mathrm{S}\sin\theta\cos\theta_6 - \mathrm{S}\cos\theta\sin\theta_6}{\mathrm{S}_5}\right) \tag{17}$$

After calculating all linear and angular positions position of output slider is given by:

$P = S_4 + S_5$

3.3 Velocity Equations

Taking time derivative of the position equation velocity equation is formulated.

The velocity of the output slider is given by V_6.

$$V_6 = S_4\cos\theta_4\omega_4 + S_5\cos\theta_5\omega_5 \tag{18}$$

$$\omega_4 = \frac{S_2\cos\theta_2\cos\theta_4\omega_2 + S_2\sin\theta_2\sin\theta_4\omega_2}{S_2}$$

It can be concluded that velocity is a function of ω_4 and input angular position of crank.

3.4 Acceleration Equations

Taking time derivative of the velocity equation acceleration equation is formulated.

The acceleration of output slider is given by A_6.

$$A_6 = -S_4\omega_4^2\cos\theta_4 - S_4\alpha_4\sin\theta_4 - S_5\omega_5^2\cos\theta_5 - S_5\alpha_5\sin\theta_5 \tag{19}$$

After obtaining the governing equations of position, velocity, and acceleration, their variations with respect to input angular position of crank are plotted in Matlab and analyzed in the chapter6.

Chapter 4
Methodology

4.1 Study of systems and works done

The existing automated machines were studied to understand the automation mechanism. All relevant mechanisms and papers in the field of linkages, design and production were studied. Mechanisms and available options are to be searched from the Internet.

4.2 Material Selections

A popular metal-ceramic system frequently used to fabricate a FGMs plate is Nickel-Alumina. Properties of Nickel and Alumina are shown in Table 4.1.

Table 4.1: Properties of Alumina and Nickel

Property	Alumina	Nickel
Composition	Al_2O_3	Ni
Density (g/cm^3)	3.96	8.9
Crystal Type	Hexagonal	FCC
Melting Temperature (˚C)	2054	1453
Elastic Modulus (GPa)	405	214
Poisson's Ratio	.26	.31
Yield Strength (MPa)	300	130
Hardness (HV)	1500	40

Anatase nanopowder TiO_2 was chosen for use as a sintering additive in part due to its easy availability and relatively low market price. In addition, previous work has indicated small quantities of TiO_2 can improve grain growth at lower temperatures in pure Alumina and reduce the sintering temperature. Some properties of TiO_2 are given in Table 3.

Table 4.2: Standard properties of TiO_2.

Property	Anatase TiO_2
Density (g/cm^3)	3.9
Crystal Type	Tetragonal
Melting Temperature (˚C)	1830
Elastic Modulus (GPa)	282
Poisson's Ratio	0.28
Yield Strength (MPa)	90
Hardness (HV)	910

4.3 Particle Size Selection

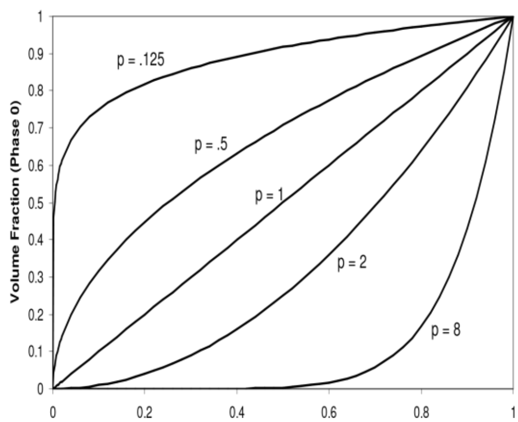
In order to produce composite microstructure, discrete layer reinforcement is needed. By controlling the particle sizes and size ratio between the matrix and inclusion phases, it is possible to achieve adequate sinter bonding in the ceramic-rich compositions and acceptable mechanical properties in the metal-rich compositions. For notation purposes, the content of a compositional element will be denoted by volume percent of Nickel. Composite elements below 50 vol. % Nickel are ceramic matrix composites (CMC) with large Nickel reinforcing particles and Elements above 50 vol. % Nickel are metal matrix composites (MMC) with large Alumina reinforcing particles. The particle sizes are presented in Table 2.

Table 4.3: Material particle size.

Material	Type	Average Particle Size (μm)
Nickel	123	3.9
Alumina	RC-HP	0.4
TiO_2	Anatase Nanopowder	0.015

4.4 Gradation Law

In producing functionally graded materials, gradation of the constituent materials is highly essential. It is because improper gradation techniques will lead to residual stresses and delamination effect. It occurs because of difference in material properties at the interfaces of metal and ceramic. So several investigations have been done in this field. Drake *et al*. [13] used power law method for the gradation purposes. The two constituent phases are represented as 0 and 1, where f_0 is the local volume fraction of phase 0, x is the distance from the phase 1 interface, t is the thickness of the gradient region, and p is an exponential parameter that controls the curvature of the gradient distribution.



Parameter(x/t)

Figure 4.1: Compositional gradients based on the power law for several values of *p*.

4.5 Design and simulation model of the apparatus

With the help of 3D modelling software the design and simulation of the components were done at each stage.

4.6 Analyze via analytical and experimental processes

Structural Analysis modules of ANSYS 14.0 were envisaged for the analytical process to find the results via Finite Element Analysis (FEA) method.

Experimental setup was made and the design was analyzed.

4.7 Schedule of the Work:

Sr No.	Activity	Estimated Time	Activity Breakup (Each box represents 2 weeks)																	
1	Study of systems and work done	6 weeks																		
2	Design of components and systems	16 weeks																		
3	Material Procurement	20 weeks																		
4	Numerical Analysis	24 weeks																		
5	Fabrication in workshop	24 weeks																		

Chapter 5

Detail Design of Components and Subsystems

To design and to fabricate a laboratory scaled experimental setup, the following techniques and processes were followed. The methodology discussed in the previous section was adopted. Here detailed fabrication techniques are presented to design the experimental set up by analysis of mechanical properties.

5.1 Design of Crank and Slotted Lever Mechanism

Design has been prepared using the software Solidworks 14 as shown in Figure 13. Dimensions of the mechanism given in the table are used for calculation of time ratio and length of the stroke. The modelling of different components of crank and slotted lever mechanism is explained here using SOLIDWORKS software. The constituent components were assembled to produce the mechanism. The mechanism was simulated in the SolidWorks software to check interference of links.

Different link dimensions which are required for crank slotted lever (quick return motion mechanism) design are given in table 5.1.

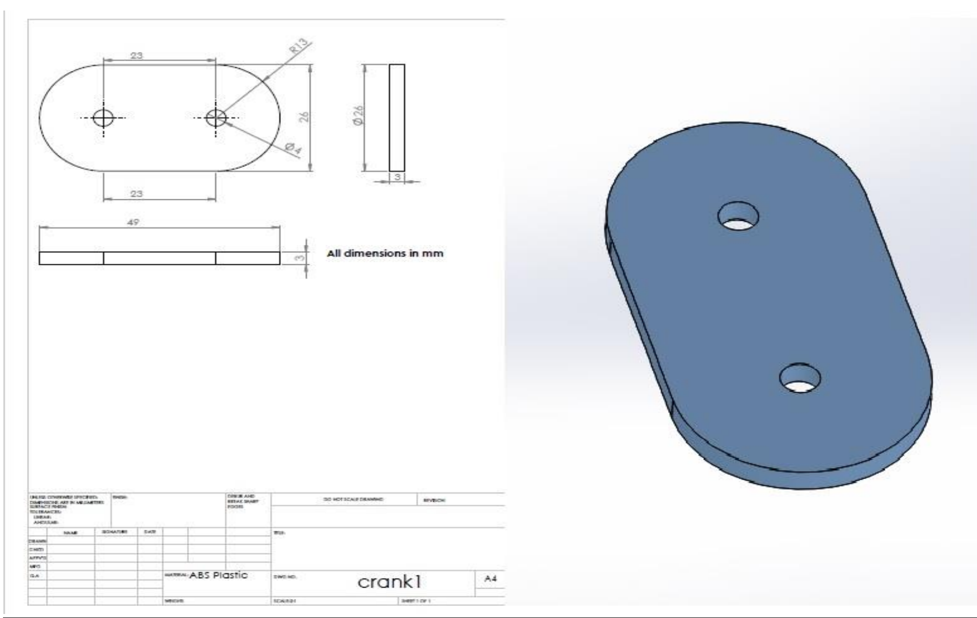
Table 5.1: Dimensions of links of crank slotted lever mechanism

SL No.	Links	Dimensions(in mm)
1	Crank	23×26×3
2	Fixed link	46×26×3
3	Slotted lever	80×45×3
4	Slider 1	25×25×20
5	Slider 2	120×90×3
6	Connecting rod	50×26×3
7	Moulding box	80×50×5

5.2 Slotted Lever Part Design

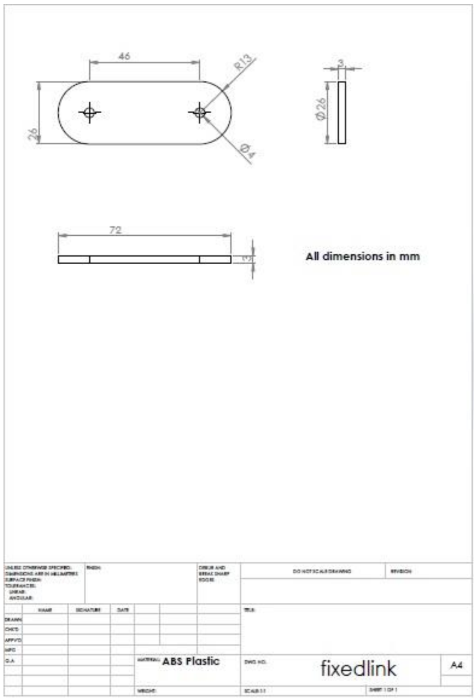
1) Crank

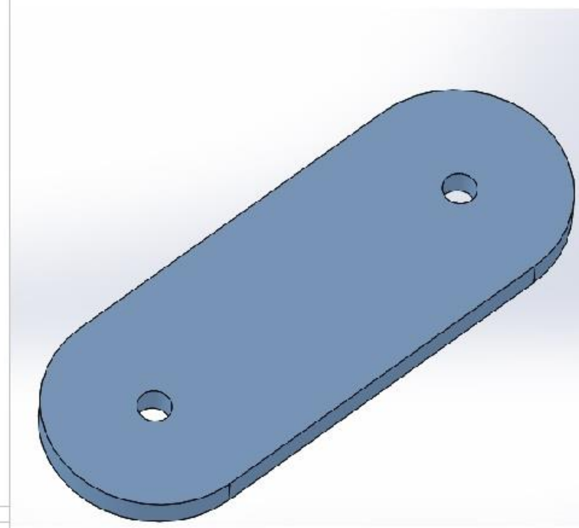
It the link where input angular velocity is provided through DC motor. The other end is fixed to the slider on the coupler.



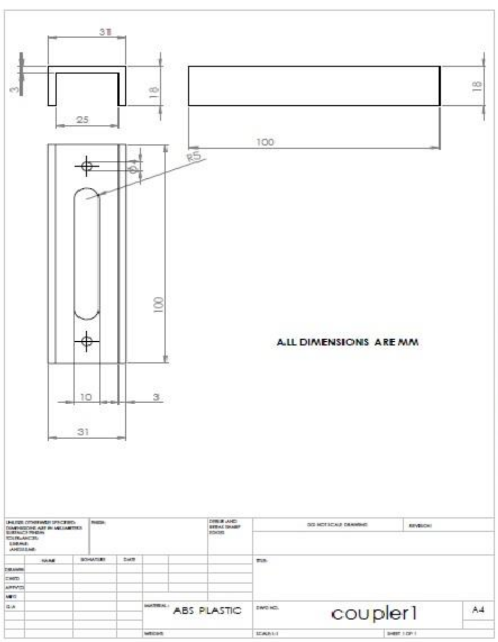
2) Fixed Link

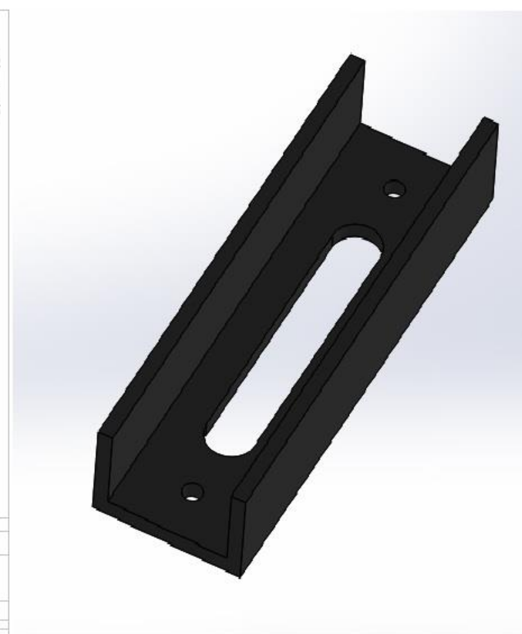
It is the fixed link in the kinematic chain.





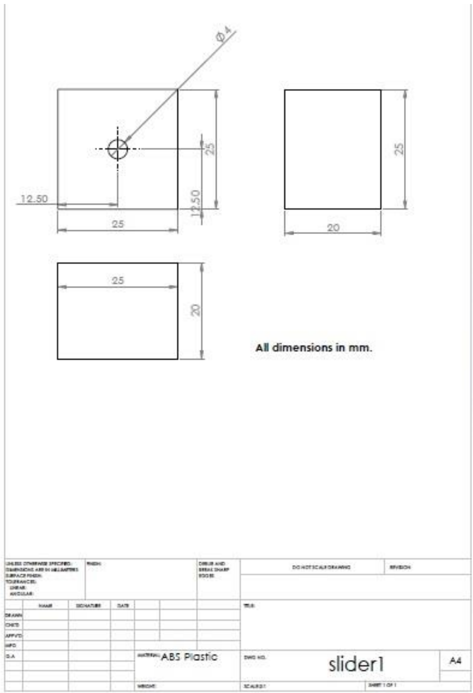
3) Coupler

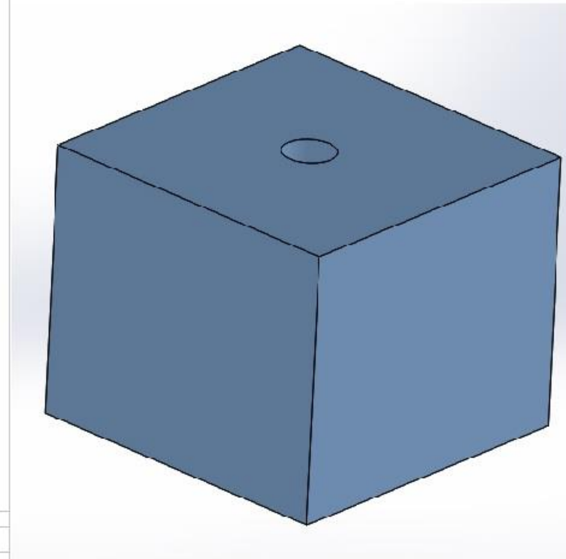




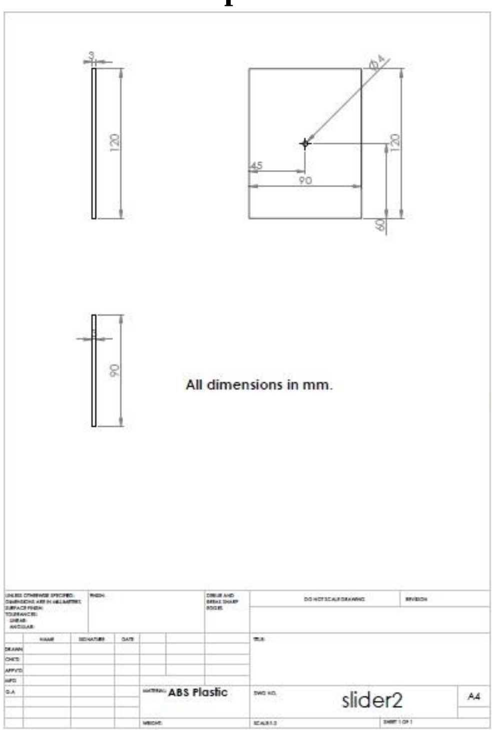
4) Slide present in slot

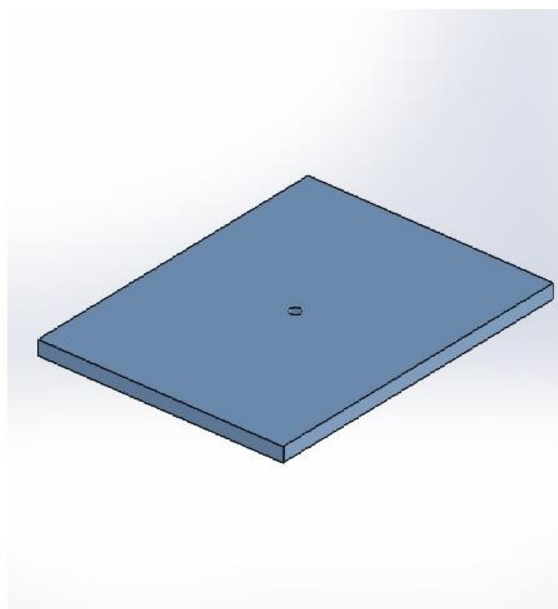
Rotation of crank causes this slider to have linear motion inside coupler.



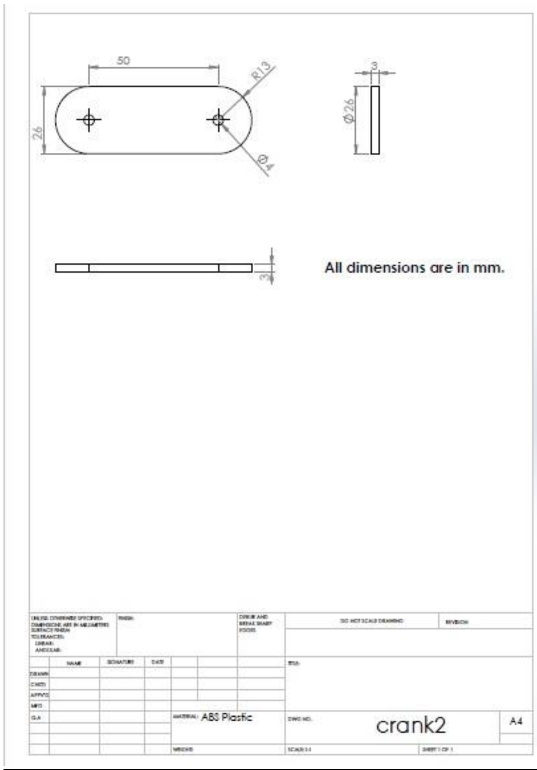


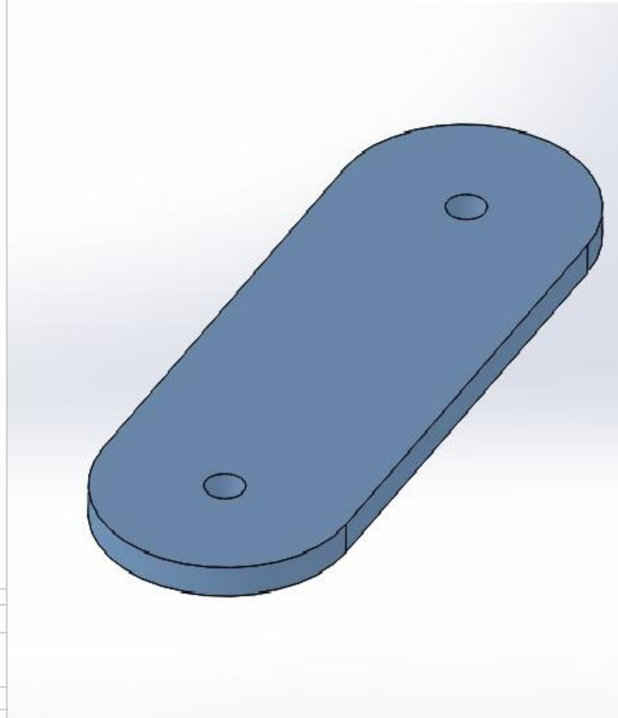
5) Slider as the output link



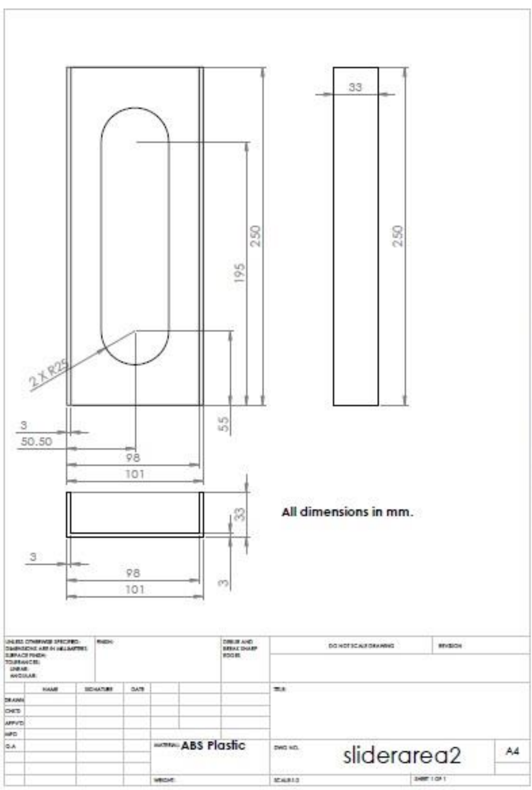


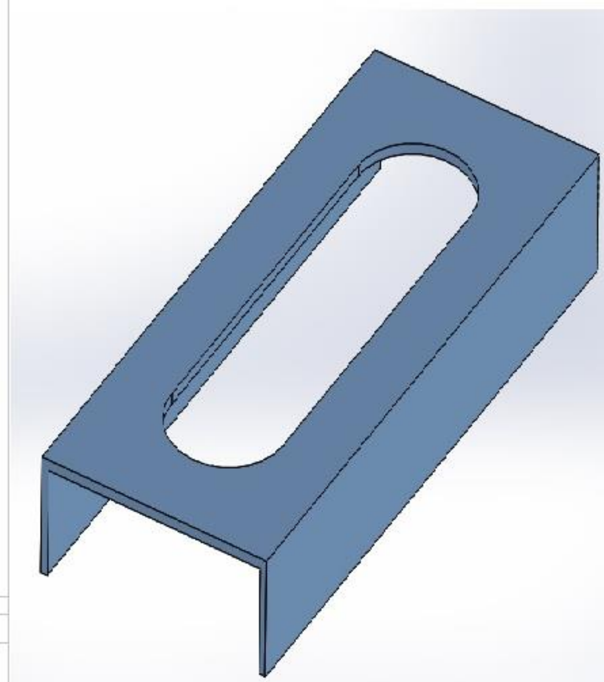
6) Crank linking coupler and slider



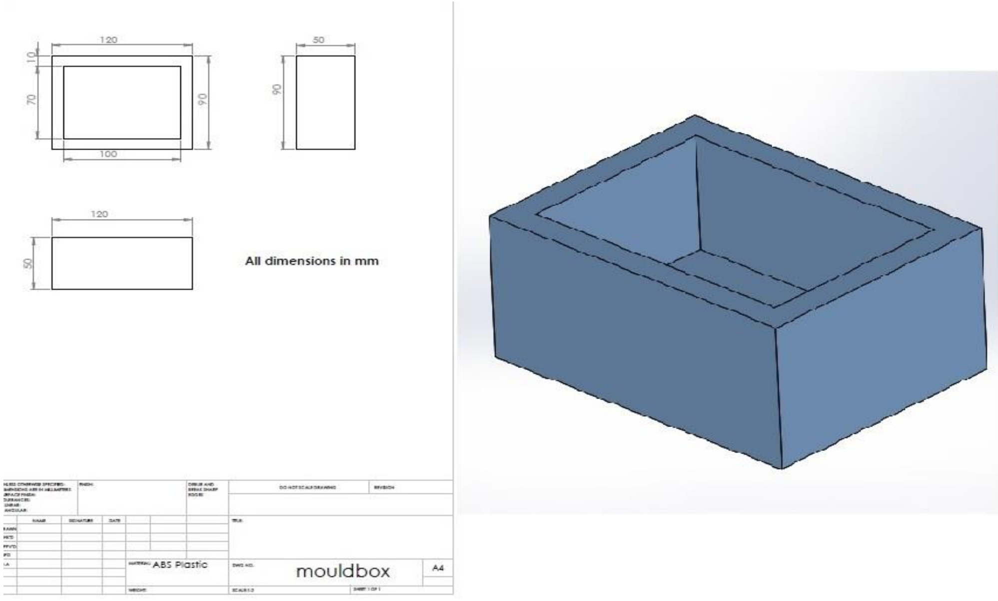


7) Slider base





8) Mould



(Figure: 5.2: Components of slotted lever mechanism**)**

5.3 Design of Nozzle

The inner inlet diameter is kept at 80mm. the thickness of the nozzle is taken as 2.5mm. The outer contour is elliptical with major and minor diameter as 50 and 9 mm respectively. The height of nozzle is taken as 80mm to maximize material flow. The inlet area is 3.5 times larger than outlet in terms of area. Given below is the nozzle system.

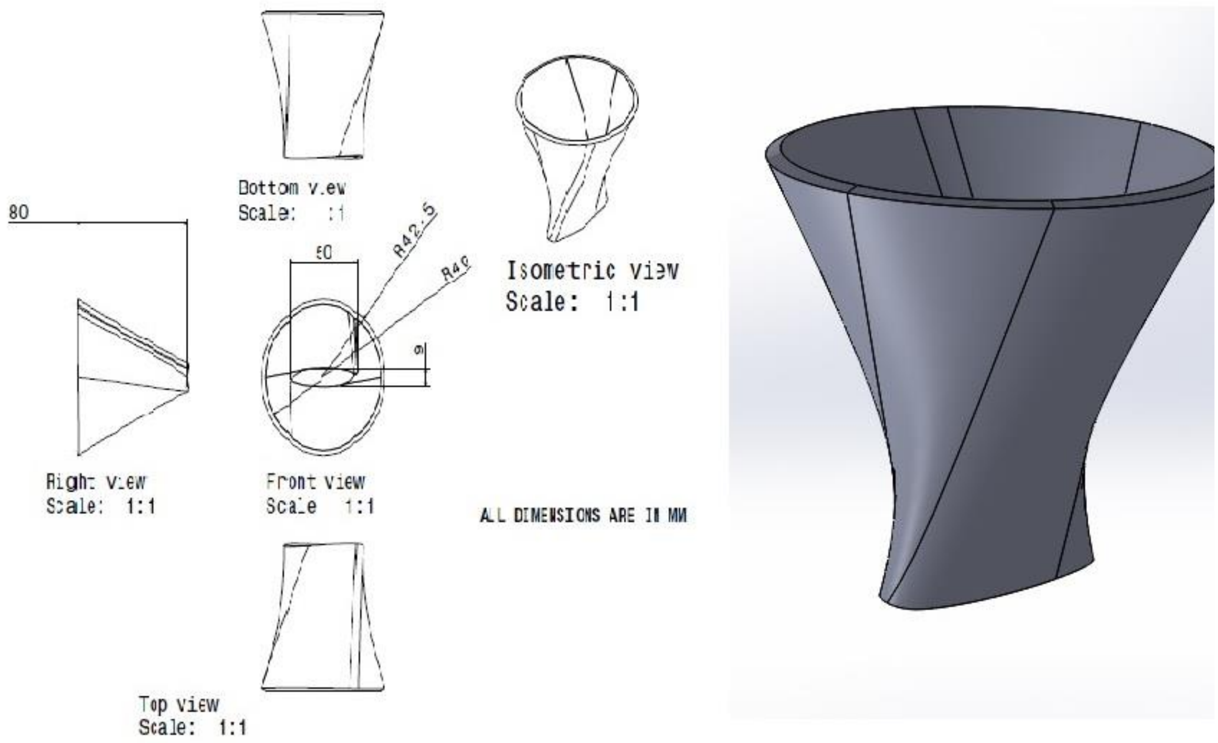


Figure 5.3: Nozzle arrangement

5.4 Specifications of the DC Motor used

Current used by motor at no running speed = 60mA

Power of 12V DC 60rpm motor $= \frac{12*60}{1000} = 0.72W$

Torque Transmitted $= \frac{0.72*60}{2*\Pi*60} = 0.1146$ Nm

5.5 Fabrication procedure of experimental set up

1) Manufacture of components using Rapid Prototyping

All the components of crank and slotted lever mechanism and nozzle were manufactured using Rapid Prototyping machine in Mechanical Engineering Department, NIT Rourkela. The material used in this process was ABS plastic. Being an additive manufacturing process, complex parts like nozzle can be manufactured without any material loss. The components manufactured have the advantage of less weight.

2) Fabrication of slotted lever mechanism

The components designed and manufactured by RP machine were assembled using 4mm bolt and screw. A DC motor was integrated with the crank. The motor was fixed with the help of pins.

3) Preparation of flow systems

PVC pipes of 40mm diameter were taken and connected to 2 funnel shaped storage lot that will contain alumina and nickel powders. These two pipes merge to a single one using three way connector, where mixing is done before flow of powder to nozzle.

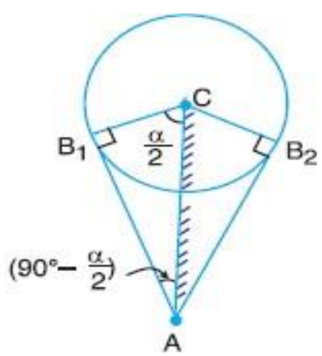
4) Integration of flow control device

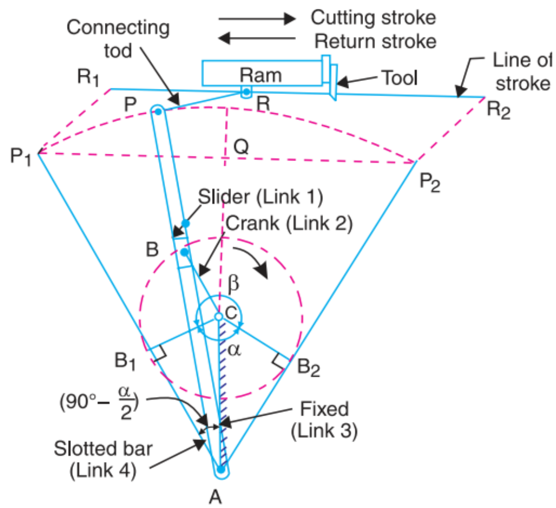
Flow control is achieved by two flow control valves at both inlet ends. The mixing ration can be set by adjustment of two valves. One more valve is present at common outlet nozzle, allowing flow only during forward stroke of quick return mechanism.

Chapter 6
Results and Discussions

6.1 Time ratio and stroke length

Let ∠CAB_1 = Inclination of the slotted bar with the vertical.





We know that

$\sin(CAB_1) = \sin(90^o - \frac{\alpha}{2})$

Hence, $\alpha = 120^o$

$$\frac{B1C}{AC} = \frac{23}{46} = 0.5$$

$<CAB_1 = (90^o - \frac{\alpha}{2}) = 30^o$

Time ratio =

$$\frac{\text{Time of Cutting Stroke}}{\text{Time of Return Stroke}} = \frac{360-\alpha}{\alpha} = \frac{360-120}{120} = 2$$

Length of stroke = $R_1R_2 = P_1P_2 = 2\ P_1Q$

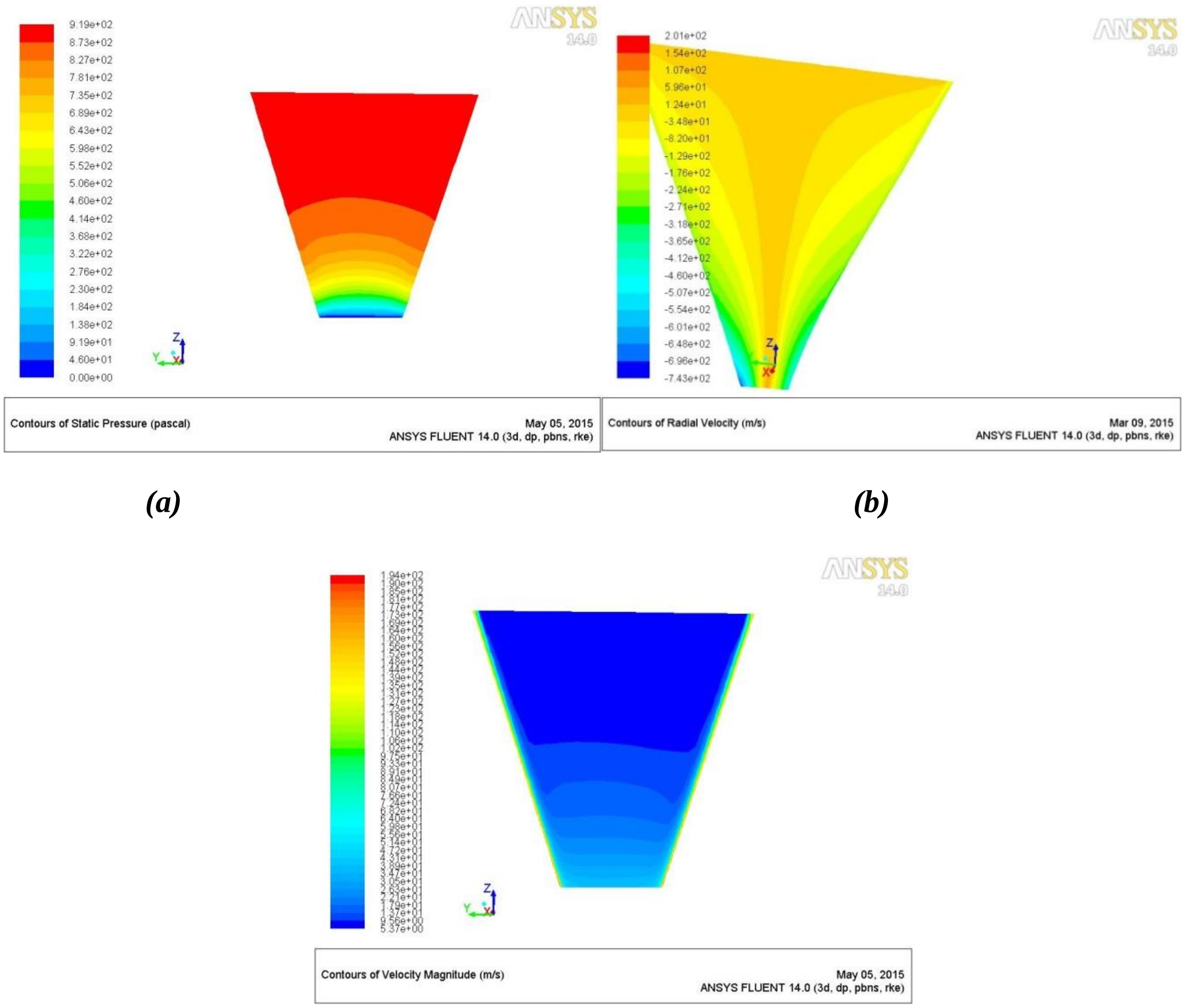
$= 2\ AP_1 \sin(90° - \frac{\alpha}{2})$

$= 2 * 80 * 0.5 = 80$ mm

6.2 Nozzle Analysis

Nozzle analysis is done using ANSYS. Nozzle model done in SolidWorks was imported to Ansys14 and graphs were plotted for pressure and radial velocity contours. For pressure contour, outlet pressure was given to be atmospheric. For velocity distribution, the inlet velocity was considered to be 6.3 m/sec. The outlet velocity is found to be 30.5m/sec. This contour is shown in figure 6.1(c). As the outlet of nozzle is exposed to atmosphere, the pressure condition at outlet is set as atmospheric. The inlet condition is calculated as 900Pa gauge pressure. This contour is shown in figure 6.1(a). The contours of radial velocity are shown in figure 6.1(b).

Ansys Plots



(a) *(b)*

(c)

Figure 6.1: (a) Pressure variation (b) Radial velocity variation (c) Velocity magnitude contours

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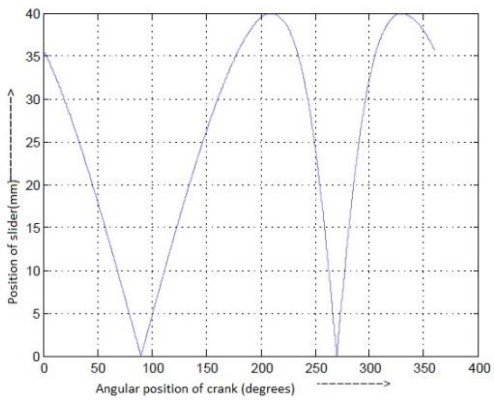
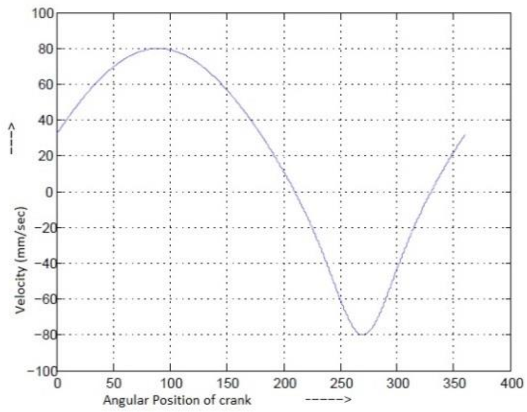
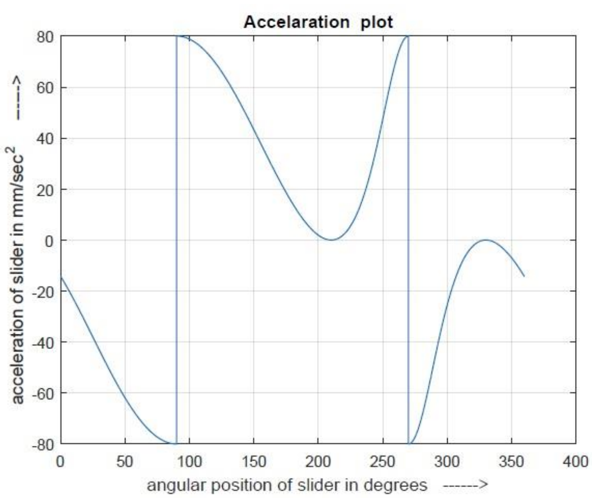
6.3 Matlab Analysis of Crank and Slotted Lever Mechanism

Matlab analysis was done for the crank and slotted mechanism for position analysis, velocity analysis and acceleration analysis. For this the mathematical formulation discussed above were used.





(a) ***(b)***



(c)

Figure 6.2: Matlab graphs for slotted lever mechanism a) position analysis b) velocity analysis c) acceleration analysis

According to the graphs plotted above, the maximum velocity of the slider was found to be 80 mm/sec, and the maximum acceleration was found to be 14.8 mm/sec^2.

6.4 Functional Setup

The slotted lever mechanism was assembled with the powder flow system. The nozzle arrangement was integrated with the flow system. A DC motor was fitted to the crank. Three flow control valves were placed at right positions in the setup. Finally the whole system was integrated and supported with wooden frame. The final setup was prepared at Central Workshop, NIT Rourkela.

Figure 6.3: Final Setup

Chapter 7

Conclusions and Scope of Future Work

Functionally graded materials, an advanced class of nonhomogeneous composite are the most researched material. They are subjected to several tests and experiments in several research studies. In this study a laboratory scale experimental setup for producing functionally graded materials was designed and fabricated. The parameter which is of foremost importance is the grading of the layers. The use of crank and slotted lever mechanism has been of great advantage towards fabrication of setup. All the necessary components were designed using solidworks and analyses has been done using matlab and ansys. Several parameters and designs are left out that can be an area of further research. The setup manufacture involved very little cost and a short span of time. This ensured that experiments can be conducted with the help of minimum cost and with a fair degree of accuracy. Functionally graded materials have a huge potential in the world of engineering applications. There is a wide scope of research in the field of development of these materials. More emphasis can be given to the automation mechanism that controls the grading of constituent materials of the composite product. This will produce desirous properties according to the need of applications.

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