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FEA and Wear Rate Analysis of Nano Coated HSS Tools for Industrial Applications

S. Ponnusamy[1], A. S. Gnana Prakash[2], P. Gokul[3], B. Gokul Mayura Priyan[4], B. Nishanthi[5]
Associate Professor[1], UG Student[2, 3, 4, 5]
Department of Mechanical Engineering
KSR Institute for Engineering and Technology, Tiruchengode, India

Abstract:
The mach inability of a material can be assessed using many output parameters of the machining process, tool life being undoubtedly the most common. Tool life depends upon mainly on the tool wear rate, which in turn is very dependent on the prevailing wear mechanisms. The Objective of this project work is to improve the machining tool performance. The HSS tool is make nano coating with materials of Zirconia and Chromium. The material strength and wear rate of HSS tool is designed and analyzed by using CATIA and FEA method (ANSYS software). The nano coated tools results shows that to improve the machining tool life.

Keywords: Tool life, Nano coating, Zirconia and Chromium.

I. INTRODUCTION

Now a day, metal cutting is a significant industry in economically developed countries, though small in comparison to the customer industries it serves. The automobile, railway, shipbuilding, aircraft manufacture, home appliance, consumer electronics and construction industries, all these have large machine shops with many thousands of employees engaged in machining. It is estimated that 15% of the value of all mechanical components manufactured worldwide is derived from machining operations. A thorough understanding of the material removal process in metal cutting is essential in selecting the tool material and in design, and also in assuring consistent dimensional accuracy and surface integrity of the finished product. Friction of metal cutting influences the cutting power, machining quality, tool life and machining cost. When tool wear reaches a certain value, increasing cutting force, vibration and cutting temperature because deteriorated surface integrity and dimension error greater than tolerance. The life of the cutting tool comes to an end. Then the cutting tool must be replaced or ground and the cutting process is interrupted. The cost and time for tool replacement and adjusting machine tool increase the cost and decrease the productivity. Hence friction in metal cutting relates to the economics of machining and prediction of friction is of great significance for the optimization of cutting process. Although various theories have been introduced hitherto to explain the wear mechanism, the complicity of the processes in the cutting zone hampers formulation of a sound theory of cutting tool wear. The nature of tool wear in metal cutting, unfortunately, is not yet clear enough in spite of numerous investigations carried out over the last 50 years. Friction of metal cutting is a result of complicated physical, chemical, and thermo-mechanical phenomena. Recently, the prediction of friction of metal cutting is performed by calculating tool life according to experiment and empirical tool life equations. Tool life equation gives no information about the wear mechanism. But capability of predicting contributions of various wear mechanism is very helpful for the design of cutting tool material and geometry. In addition, such tool life equations are valid under very limited cutting conditions. For example, when tool geometry is changed, new equation must be established by making experiment.

Figure. 1.1 Machining Operation

A. CUTTING TOOL

Cutting tool materials are materials that are used to make cutting tools that are used in machining (drill bits, tool bits, milling cutters, etc.) but no other cutting tools like knives or punches. Cutting tool materials must be harder than the material of the work piece, even at high temperatures during the process. Cutting tool users can't afford to ignore the constant changes and advancements that are being made in the field of tool material technology. When a tool change is needed or anticipated, a performance comparison should be made before selecting the tool for the job. Many types of tool materials, ranging from high carbon steel to ceramics and diamonds, are used as cutting tools in today's metalworking industry. It is important to be aware that differences do exist among tool materials, what these differences are, and the correct application for each type of material. The various tool manufacturers assign many names and numbers to their products. While many of these names and numbers may appear to be similar, the applications of these tool materials may be entirely different. In most cases, the tool manufacturers will provide tools made of the proper material for each given application. In some particular applications, a premium or higher priced material will be justified.

Figure.1.2. Cutting Tools

A cutting tool must have the following characteristics in order to produce good quality and economical parts:

Hardness - harness and strength of the cutting tool must be maintained at elevated temperatures, also called hot hardness.

Toughness - toughness of cutting tools is needed so that tools don't chip or fracture, especially during interrupted cutting operations.

Wear Resistance - wear resistance means the attainment of acceptable tool life before tools need to be replaced.

B. HIGH SPEED STEEL

HSS tools**,** a cutting material for machining process, it is often used in power-saw blades and drill bits. High speed steels are alloys that gain their properties from either tungsten or molybdenum, often with a combination of the two. The main use of high-speed steels continues to be in the manufacture of various cutting tools: drills, taps, milling cutters, tool bits, gear cutters, saw blades, planer and jointer blades, router bits, etc., High-speed steel (HSS or HS) is a subset of tool steels, commonly used as cutting tool material. It is often used in power-saw blades and drill bits. It is superior to the older high-carbon steel tools used extensively through the 1940s in that it can withstand higher temperatures without losing its temper (hardness). This property allows HSS to cut faster than high carbon steel, hence the name high-speed steel. At room temperature, in their generally recommended heat treatment, HSS grades generally display high hardness (above Rockwell hardness 60) and abrasion resistance (generally linked to tungsten and vanadium content often used in HSS) compared with common carbon and tool steels.

C. NEEDS OF HSS

The need for tool materials that could withstand increased cutting speeds and temperatures led to the development of high-speed tool steels (HSS). The major difference between HSS and plain high carbon steel is the addition of alloying elements to harden and strengthen the steel and make it more resistant to heat (hot hardness). Some of the most commonly used alloying elements are manganese, chromium, tungsten, vanadium, molybdenum, cobalt, and niobium. While each of these elements will add certain specific desirable characteristics, it can be generally states that they add deep hardening capability, high hot hardness, resistance to abrasive wear, and strength, to HSS. These characteristics allow relatively higher machining speeds and improved performance over plain high carbon steel. The most common HSS used primarily as cutting tools are divided into the M and T series. The M series represents tool steels of molybdenum type and the T series represents Tungsten. Although there seems to be a great deal of similarly among these HSS, each one serves a specific purpose and offers significant benefits in its special application. An important point to remember is that none of the alloying elements for either series of HSS is in abundant supply and the cost of these elements is skyrocketing. In addition, U.S. manufacturers must rely on foreign countries for supply of these very important elements.

D. HSS TREATMENT

Many surface treatments have been developed in an attempt to extend tool life, reduce power consumption, and to control other factors that affect operating conditions and costs. Some of these treatments have been used for many years and have proven to have some value. For example, the black oxide coatings that commonly appear on drills and taps are of value as a deterrent to build-up on the tool. The black oxide is basically 'dirty' surface that discourages the build-up of work material. One of the more recent developments in coatings for HHS is titanium nitride by the physical vapor deposition (PVD) method. Titanium nitride is deposited on the tool surface in one of several different types of furnace at relatively low temperature, which does not significantly affect the heat treatment (hardness) of the tool being coated. This coating is known to extend the life of a cutting tool significantly or to allow the tool to be used at higher operating speeds. Tool life can be extended by as much as three times, or operating speeds can be increased up to 50%.

E. CAST ALLOYS

The alloying elements in HSS - principally cobalt, chromium, and tungsten - improve the cutting properties sufficiently, that metallurgical researchers developed the cast alloys, a family of materials without iron. A typical composition for this class was 45% cobalt, 32% chromium, 21% tungsten, and 2% carbon. The purpose was to obtain a cutting tool with hot hardness superior to HSS. When applying cast alloy tools, their brittleness should be kept in mind and sufficient support should be provided at all times. Cast alloys provide high abrasion resistance and are thus useful for cutting scaly materials or those with hard inclusions.

II. LITERATURE SURVEY

Ivin S Bovas, Anoop M R, "Wear Rate Analysis of Nano-Coated Cutting Tool":Drilling is one of the metal cutting operations that are widely used manufacturing technique in the industrial world. In this process, drill bits are the cutting tools that are used to create circular holes. The aim of the present work is to minimize the tool wear rate by nano-coating TiAlN on the tool surface. For that wear tests are conducted on the pin-on-disc apparatus under dry sliding condition. The surface morphology of the tools was studied by using Scanning Electron Microscopy (SEM). With the help of ANSYS Workbench 14.0 the frictional stress and contact pressure for both TiAlN coated and uncoated HSS pins were analysed for different varying loads. It was found that TiAlN nano-coated tool shows very less wear rate than HSS cutting tool.[1]

M.Yugandhar, N.Harish Kumar - "Study of Mechanical and Tribological Properties of Coated TiN and TiC on cutting tools by varying the composition of Nickel and Carbon":It has been well established that advanced surface coatings on cutting tools improve wear resistance by modifying the contact conditions between the chip and tool interface. As a result of the recent developments in cutting tool industry, coated tools have made a significant contribution to the metal cutting operations in terms of tool life, cutting time and machining quality. The challenge of modern machining industries is focused mainly on the achievement of high quality, in terms of work piece dimensional accuracy, surface finish, high production rate, less wear on the cutting tools, economy of machining in terms of cost saving and increase the performance of the product .In general, the most important point in machining processes is the productivity, achieved by cutting the highest amount of material in the shortest period of time using tools with the longest lifetime. The present research work describes the development, Mechanical, Tribological performance of Nanomaterial coating of (Titanium Nitride), TiC (Titanium Carbide), on Tungsten Carbide cutting tool. The Mechanical, Tribological properties of Tin, TIC, are to be compared with uncoated Tungsten carbide cutting tool. And also different coating methods like Chemical Vapor Deposition, Physical Vapor Deposition Method, can be used for comparison. The present work will help to find the tool life and wear behavior of the each coated tool and it will help to find the best tool coating applicable for the cutting tool. The experiments of Mechanical, Tribological properties tests have to be conducted as per ASTM standards. Scanning Electron microscope (SEM) analysis has to be done for investigating the surface morphology of Tungsten Cutting tool. The coated cutting tools have to be modelled using suitable assumption and analysed by means of finite element method using ANSYS software. Both results of Experimental and ANSYS software are to be compared. [2] VikasPatidar, Prof. Kamlesh Gangrade, Dr. Suman Sharma - "Wear Analysis of Multi Point Milling Cutter using FEA": The material removal process uses cutting tools in order to produce the desired shape of the work piece. Tool wear has been a problem for cutting tools, since cutting tools wear and break. Research has been accomplished in the tool wear field for tool life and more recently tool wear. The computer generation has created a method to simulate the material removal process. These computer simulations model the cutting tool reaction with the work piece. Many of the simulation models use finite element analysis to calculate the reaction of the cutting tool. Different finite element models are being used throughout the world for research. In this Paper the design aspects of surface milling cutter is analysed. The objective considered is the design and modelling of surface milling cutter and to analyse various stress components acting on it. [3]Kyung Hee Park, "tool wear analysis in various machining processes and study of minimum quantity lubrication (MQL)":The tool wear analysis on the multilayer coated carbide inserts in turning and milling of AISI 1045 steels was performed using advanced microscope and image processing techniques. In turning process, the flank wear evolution, surface roughness and groove sizes on the coating layers were analyzed to understand the flank wear mechanism(s) involved. The dominant wear phenomenon was abrasion and, after carbide was exposed, adhesion took over. For flank wear prediction, 2-body abrasion model was used along the interface conditions from finite element (FE) model, which provides the temperature on the cutting tool. In a face milling study, multilayer cutting tools, double (TiN/TiAlN) and triple (TiN/Al2O3/TiCN) layered coated carbide, processed by physical vapor deposition (PVD) and chemical vapor deposition (CVD) respectively, were evaluated in terms of various cutting conditions. Similar to the turning case, abrasion was found to be the most dominant tool wear mechanism in milling. Edge chipping and micro-fracture were the tool failure modes. Overall, the double layer coating was superior to the triple layer coating under various cutting conditions due to the benefit coming from the coating deposition processes themselves.[4]

III. PROPOSED METHODOLOGY

The nano coating process of HSS tool with Zirconia and chromium materials because the life of high-speed steel can be prolonged by coating the tool. A coating is a covering that is applied to the surface of an object, usually referred to as the substrate. The purpose of applying the coating may be decorative, functional, or both. The coating itself may be an all-over coating, completely covering the substrate, or it may only cover parts of the substrate.

IV. MATERIAL SELECTION

Tool steel refers to a variety of carbon and alloy steels that are particularly well-suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion and deformation, and their ability to hold a cutting edge at elevated temperatures. As a result, tool steels are suited for use in the shaping of other materials. With carbon content between 0.5% and 1.5%, tool steels are manufactured under carefully controlled conditions to produce the required quality. The presence of carbides in their matrix plays the dominant role in the qualities of tool steel. The four major alloying elements that form carbides in tool tungsten, chromium, vanadium and molybdenum. The rate of dissolution of the different carbides into the austenite form of the iron determines the high-temperature performance of steel (slower is better, making for a heat-resistant steel). Proper heat treatment of these steels is important for adequate performance. The manganese content is often kept low to minimize the possibility of cracking during water quenching. There are six groups of tool steels: water-hardening, cold-work, shock-resistant, high-speed, hot-work, and special purpose. The choice of group to select depends on cost, working temperature, required surface hardness, strength, shock resistance, and toughness requirements. The more severe the service condition (higher temperature, abrasiveness, corrosiveness, loading), the higher the alloy content and consequent amount of carbides required for the tool steel. High-speed steel (HSS or HS) is a subset of tool steels, commonly used as cutting tool material. This property allows HSS to cut faster than high carbon steel, hence the name high-speed steel. At room temperature, in their generally recommended heat treatment, HSS grades generally display high hardness (above Rockwell hardness 60) and abrasion resistance (generally linked to tungsten and vanadium content often used in HSS) compared with common carbon and tool steels.

F. ZIRCONIA

Zirconia is a white powdered material commonly used to produce dental frameworks for dental substructures such as crowns, bridges, etc. Unlike standard ceramics Zirconium oxide ceramics also have very high thermal expansion Zirconia-based ceramics are also used in many other applications. For instance, they can be used as auxiliaries in welding processes, as tools for wire forming, as oxygen measurement cells and are therefore often the material of choice for joining ceramic and steel. Pure zirconia is found in three crystal phases at different temperatures and they include Monoclinic, Cubic and Tetragonal. The fine grain size enables the material to have sharp edges and very smooth surfaces. In order to prevent and control structural changes, several different oxides can be dispersed into the zirconia crystal structure during production. These oxides include Ceria, Magnesia and Yttria. Zirconia-based ceramics are also used in many other applications. These ceramics have been developed to such an extent that infinite designs of micro structure are now possible by controlling fabrication route, composition, thermal treatment, and final machining.

G. CHROMIUM

Chromium is a chemical element with Cr as its symbol. It belongs to group 6, periodic number 4 of the periodic table. Its atomic number is 24. Chromium is a steely-gray lustrous, brittle, hard metal. It is known to have high corrosion resistance. When polished, it gains a very shiny surface, which is used to plate other metals so as to form a protective and attractive covering. Chromium is mined as chromite ore. Globally this ore is available in India, South Africa, Finland, Zimbabwe, Kazakihstan and the Philippines. Commercially, chromium is produced from chromite using silicothermic or aluminothermy reactions. Roasting and leaching processes are also used.

V. MATERIAL PROPERTIES

ZIRCONIUM

Density	56.8 kg/m^3
Melting Point	2715^0C
Tensile Strength	330 Mpa
Poisson Ratio	0.32
Thermal Conductivity	16.7 W/mK

CHROMIUM

Density	7.19 kg/m^3
Melting Point	1907^0C
Modulus of Elasticity	248 Gpa
Poisson Ratio	0.22
Thermal Conductivity	69.1 W/Mk

VI. FINITE ELEMENT ANALYSIS

The Finite Element Method (FEM) is a numerical method for solving problems of engineering and mathematical physics. Typical problem areas of interest include structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. The analytical solution of these problems generally requires the solution to boundary value problems for partial differential equations. The finite element method formulation of the problem results in a system of algebraic equations. The method approximates the unknown function over the domain. To solve the problem, it subdivides a large system into smaller, simpler parts that are called finite elements. The simple equations that model these finite elements are then assembled into a larger system of equations that models the entire problem. FEM then uses variation methods from the calculus of variations to approximate a solution by minimizing an associated error function.

VII. MODELING AND ANALYSIS

The 3D model of HSS tool is designed by using CATIA software. CATIA, one of the best 3D integrated software and choice of mechanical modelling work. It creates better visualization of 3D model of component and performs best for FEA work. The Finite Element Analysis work is done with the ANSYS software. The structural analysis is done with the proposed HSS tool.

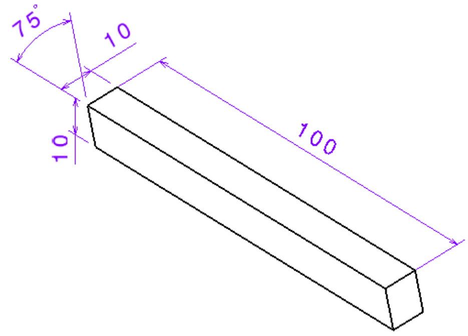

Figure.7.1 2D Design tool

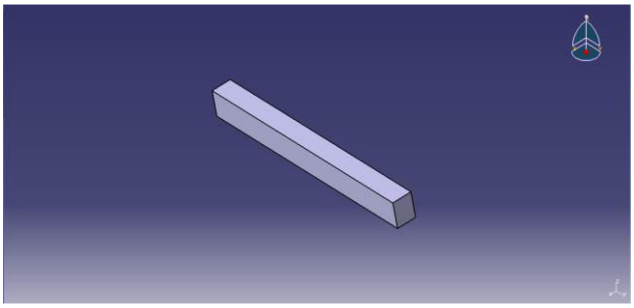

Figure.7.2 Specimen without Coating

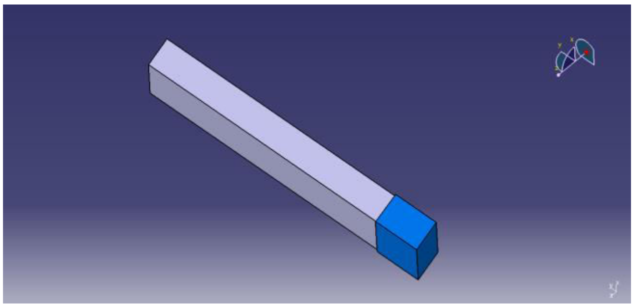

Figure.7.3 Specimen with Coating

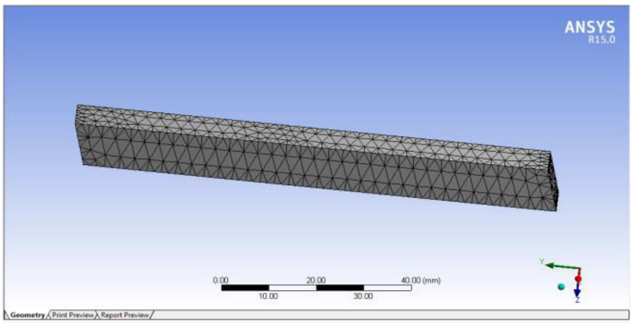

Figure.7.4. Mesh Geometry (Uncoated Specimen)

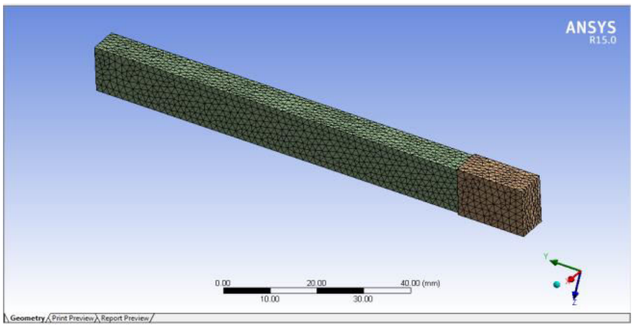

Figure.7.5 Mesh Geometry (Coated Specimen)

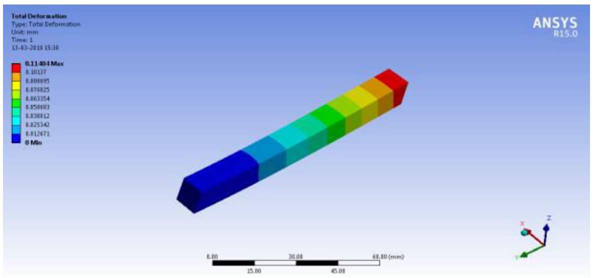

Figure.7.6 Deformation of Uncoated Specimen

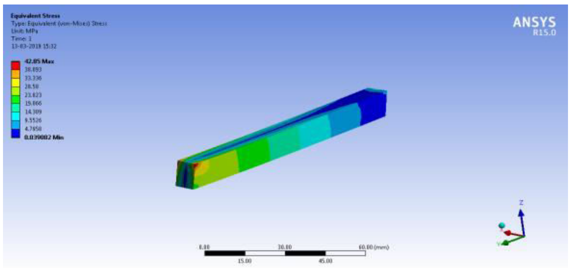

Figure.7.7 Stress of Uncoated Specimen

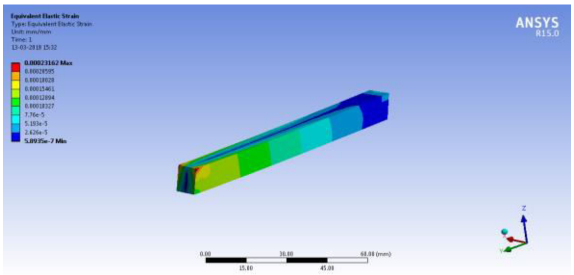

Figure.7.8 Strain of Uncoated Specimen

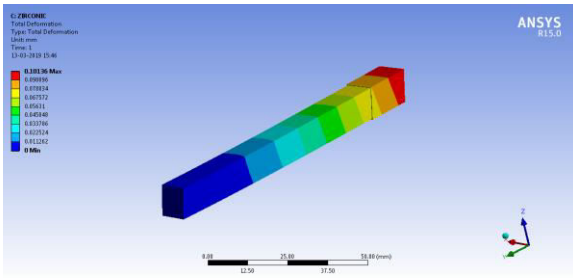

Figure.7.9 Deformation of Zirconia Material

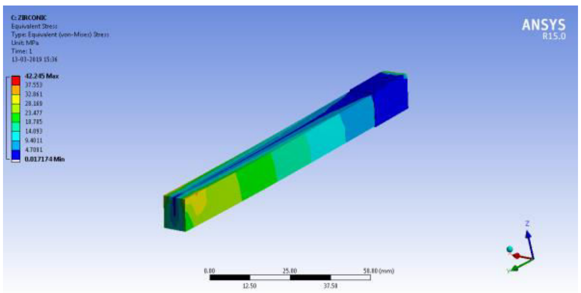

Figure.7.10Stress of Zirconia Material

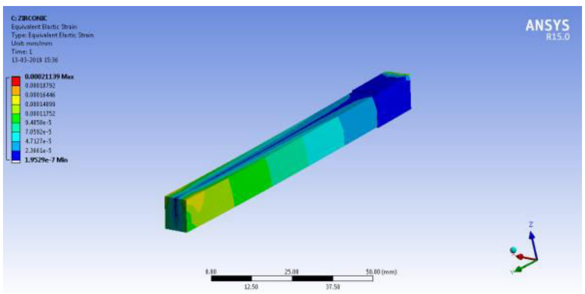

Figure.7.11 Strain of Zirconia Material

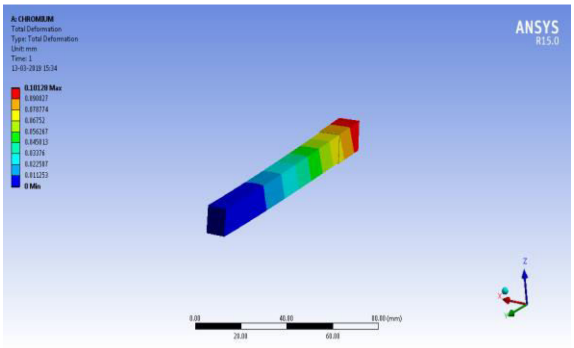

Figure.7.12 Deformation of Chromium Material

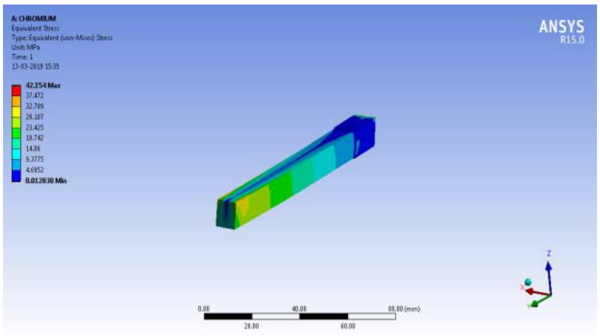

Figure.7.13 Stress of Chromium Material

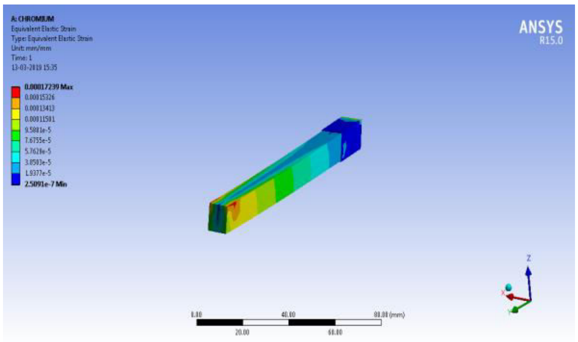

Figure.7.14 Strain of Chromium Material

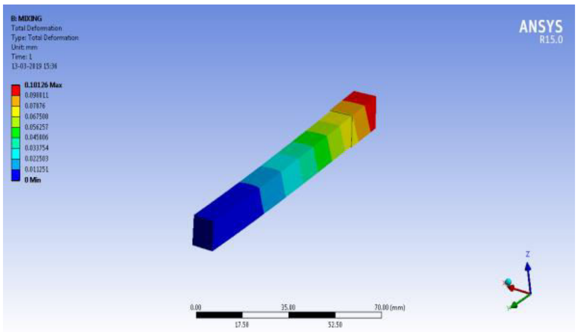

Figure.7.15 Total Deformation of Zr-Cr

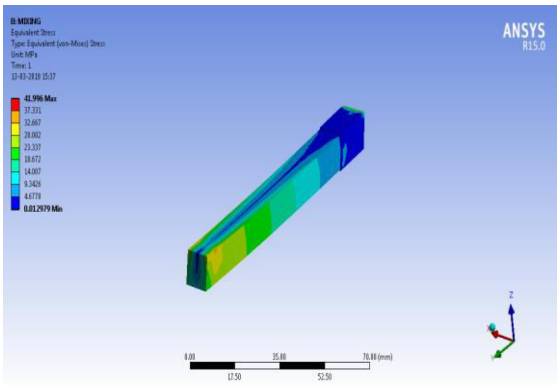

Figure.7.16 Stress of Zr-Cr

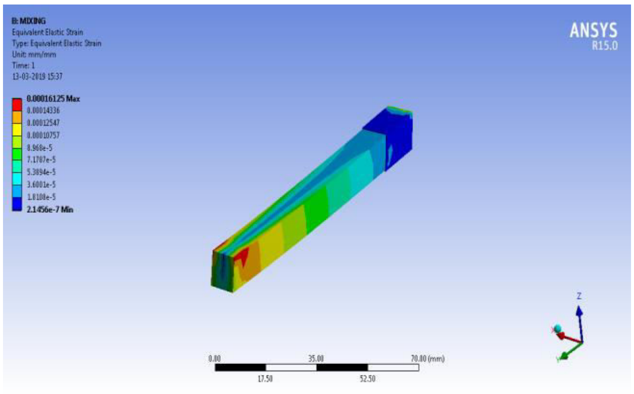

Figure.7.17 Elastic Strain of Zr-Cr

VII. RESULT & DISCUSSION

Table 8.1 HSS Tool Results without Coating

Materials Without coating	Total Deformation Mm	Stress (Mpa)	strain
Hss Without coating	0.114	42.85	0.0023

Table 8.2 HSS Tool Results WithCoating

Materials coating	Total deformation	Stress (Mpa)	Strain
Zirconia	0.1013	42.245	0.000211
Chromium	0.1012	42.154	0.00014
Zr-Cr	0.1012	41.996	0.00016

VIII. CONCLUSION

Now a days, metal cutting is a significant industry in economically developed countries, though small in comparison to the customer industries it serves. The automobile, railway, shipbuilding, aircraft manufacture, home appliance, consumer electronics and construction industries, all these have large machine shops with many thousands of employees engaged in machining. Here, the HSS tool of proposed system will give better performance of machining. Also we can suggest the best and advanced tool for machining process through this present project work.

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