Design Modeling and Experimental Analysis of an End Milling Cutter

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ABSTRACT

Milling is a machining process in which metal is removed bya turn round milling cutter. The cutter has a number of fragment edges, which engross with the work piece only in a part of its rotary path, the remainder being through air. This results in the pulsation of cuttingforces. During the entire milling process cutting forces is one of the most important issue.The forces acting on the tool are an important aspect of machining. The cutting forces vary with the tool angle and accurate measurement of forces is useful in optimizing Tool Design. The modelling and analysis of a milling cutter increases the efficiency of cutting operations. This paper presents the practical investigation of modelling and design analysis of End Mill cutterby calculating the cutting forces for two different materials namely Highspeed Steel(HSS)and plain Carbon Steel. Other parameters such as cutting speed (Vs),feed rate (Sm),chip thickness(a),SpindleSpeed(n),Metal RemovalRate(Q) are calculated.The objective of this paper is to analyze the stress components andstrains acting on End-mill cutter with varying loads.TheProbing investigation resultsby make use of CATIA and ANSYS.

key words: *Tool material, cutting force, High Speed Steel, Plain Carbon Steel, End-Milling Cutter, ANSYS, CATIA*

INTRODUCTION

Milling is a process of producing flat and complex shapes with the use of multi-tooth cutting tool, which is called a milling cutter and the cutting edges are called teeth. The axis of rotation of the cutting tool is perpendicular to the direction of feed, either parallel or perpendicular to the machined surface.The interrupted cutting action subjects the teeth to a cycle of impact force and thermal shock on every rotation. The tool material and cutter geometry must be designed to withstand these conditions. Cutting fluids are essential for most milling operations. The cutter design being presented in this paper is useful for single point as well as for multi-point cutters such as those used for turning and milling. The design parameters such as rake angle, clearance angle of tooth, and height of tooth are common in both single point and multi-point cutters. Additionally, parameters such as speed of rotation, feed, and depth of cut are also similar. However, parameters such as diameter of the cutter, number of teeth on the cutter, and angular spacing of teeth are exclusively associated with milling cutters.

Development and improvements of the milling machine and components continued, which resulted in the manufacturing of heavier arbors and high speed steel and carbide cutters and cutting speed.Milling is the process of machining flat, curved.Milling machines are classified as knee-type, cutter containing a number of cutting edges. Most of the milling machines consists basically of a motor driven spindle, which milling machines have self-contained electric drive motors, mounts and revolves the milling cutter, and a reciprocating coolant systems, which mounts on the work table and feeds the work piece, table feeds [1,2]. This paper aims to develop an experimental optimum geometric model of a plain cutter based on the industrial applications. To overcome these difficulties associated with modeling a complex cutter, an interface in the form of a customized Tool Design model is developed. This design tool can render the threedimensional geometry of the cutter in any commercial CAD environment for validation and design improvements. In this research work, the proposed 3D model of the special shaped milling cutter is used for finite element analysis to optimize its design. The experimental results of stress distribution and deformation are presented.

Fig.Working motions of plain milling operation

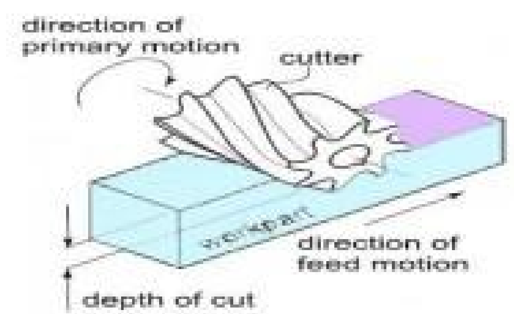


Fig. Depth of cut of plain milling cutter

Literature Review

Mohammed and Tandon (2000) developed geometric design model of a brazed insert-based CEFM cutter in terms of three-dimensional (3D) parameters. The model defined the CEFM cutter in terms of 3D rotational angles and also developed a provision of interface of 3D CEFM cutter directly for the purpose of methodology validation. Finite element analysis (FEA) was used to determine the effects on cutting insert under transient dynamic load conditions. [3] Mohammed and Tandon (2000) proposed a shape design methodology in order to develop the geometry of a generic special shaped milling cutter. The proposed three-dimensional parametric definition of the cutter with varying the rake angle of the insert and insert seat was analyzed using FEM. Though there is a good amount of work is done by the researcher to study and develop the various models for the conventional single point and multipoint cutting tools, but a few works have not been covered on the development of special shaped milling cutter model. [4]

TYPES OF MILLING PROCESSES

There are two basic types of milling, are as follows¬

Down (climb) milling: It is type of milling in which the cutter rotation is in the same direction as the motion of the work piece being fed. In down milling, the cutting force is directed into the work table, which allows thinner work parts to be machined.

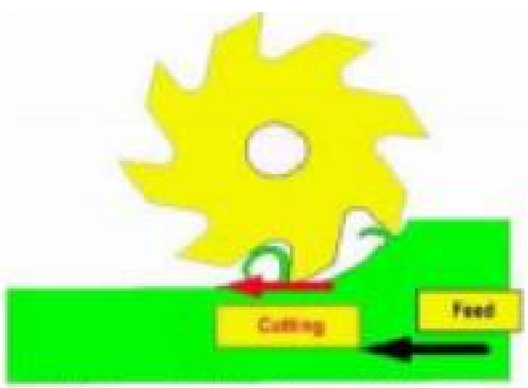


Fig.3 Down Milling (Climb Milling)

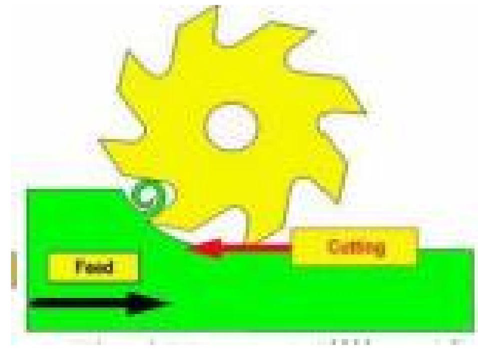
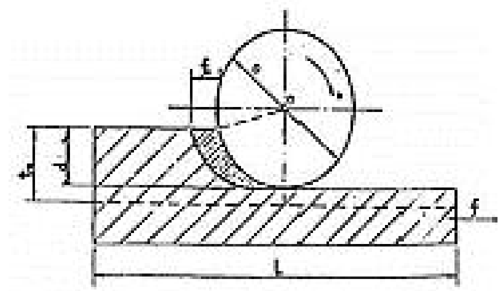


Fig. Up cut Milling (Conventional Milling)

Up (conventional) milling: It is the type of



milling in which the work piece is moving towards the cutter, opposing the cutter direction of rotation. In up milling, the cutting force tends to lift the work piece. The work conditions for the cutter are more favourable.

Types of End Milling Cutters

1. **End Milling Cutters:** End milling cutters, also called end mills, have teeth on the end as well as the periphery. End milling cutters have shanks for chuck mounting or direct spindle mounting.. End milling cutters are employed in the production of slots, keyways, recesses, and tangs. They are also used for milling angles, shoulders, and the edges of work pieces.

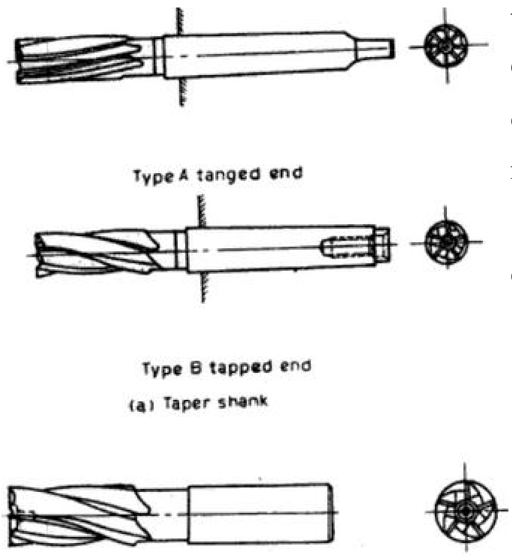
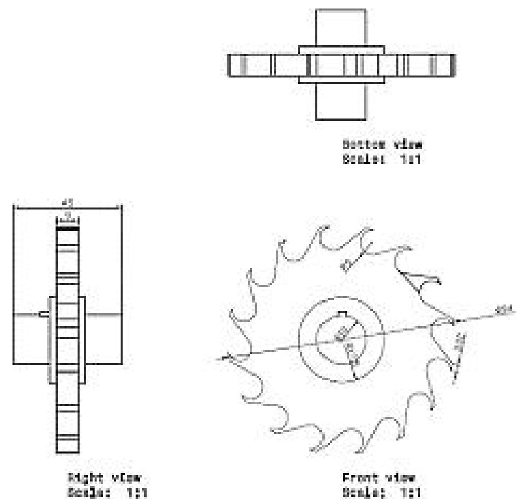


Figure: End Milling Cutter

Material Selection

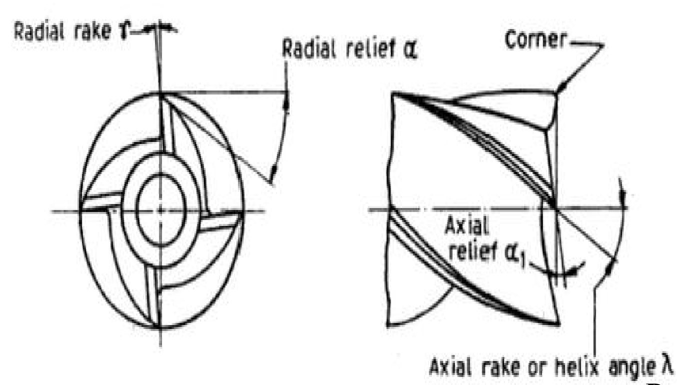
- Material
    1. High Speed Steel
    2. Plain Carbon Steel
- Composition
    1. HSS – (18% Tungsten, 4% Chromium,1% Vanadium, 0.1% Carbon, rest Iron)
    2. Plain Carbon Steel – (0.9 Carbon, 1% Manganese)

In this experimental work, a customized tool design for end mill cutter has been designed and developed. This design tool helps in rendering the proposed three-dimensional model, defined with the help of parametric equations, in any CAD environment by suitable translation of the experimental geometric data of the cutter. This milling cutter design will also help in *validating*the mathematical models and experimental work



CUTTING VARIABLES OF END MILLING

In milling, each tooth on a tool removes part of the stock in the form of a chip. The basic interface between tool and work part is pictured below. This shows a only a few teeth of a



peripheral milling cutter.

Cutting Velocity

Cutting velocity V is the peripheral speed of the cutter is defined by V = πDN

Cutting Speed

Cutting speed of a milling cutter is its peripheral linear speed resulting from operation. It is expressed in meters per minute. The cutting speed can be derived from the above formula. Spindle speed of a milling machine is selected to give the desired peripheral speed of cutter.V = (πdn)/1000 Where d = Diameter of milling cutter in mm, V = Cutting speed (linear) in meter per minute, and n = Cutter speed in revolution per minute.

Feed Rate

It is the rate with which the work piece under process advances under the revolving milling cutterFeed is expressed in three ways

Feed per Tooth

It is the distance traveled by the work piece (its advance) between engagement by the two

Feed per Revolution

Travel of work piece during one revolution of milling cutter. It is expressed as mm/rev. and denoted by f(rev).

Feed per Unit of Time

Feed can also be expressed as feed/minute or feed/sec. It is the distance advances by the work piece in unit time (fm).

Above described three feed rates are mutually convertible.

f m × n×frev

Where n = rpm of cutter.

It can be extended further as

Feed rate (F) is defined as the rate of travel of the work piece in mm/min.

But most tool suppliers recommend it as the movement per tooth of the cutter (f). Thus,

F = f. u. N

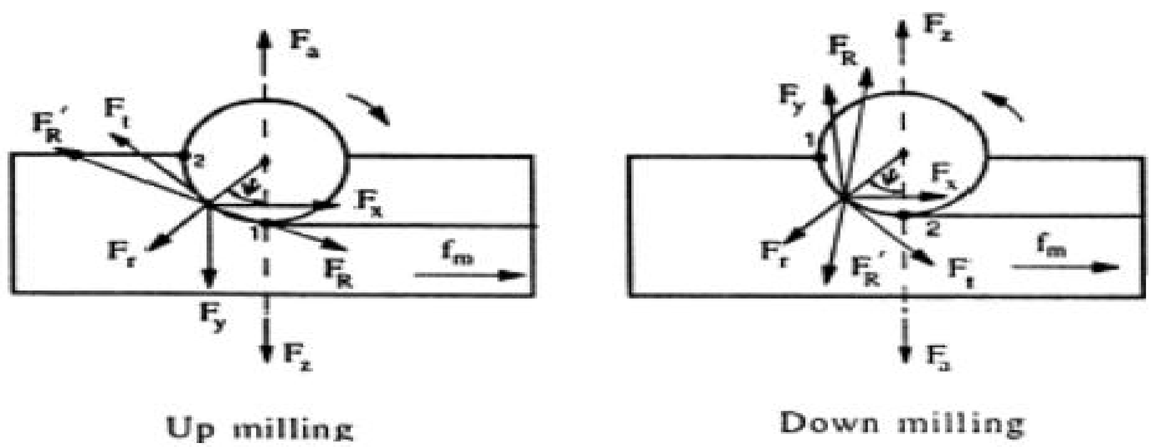
where, F= table feed in mm/min

f= movement per tooth of cutter in mm

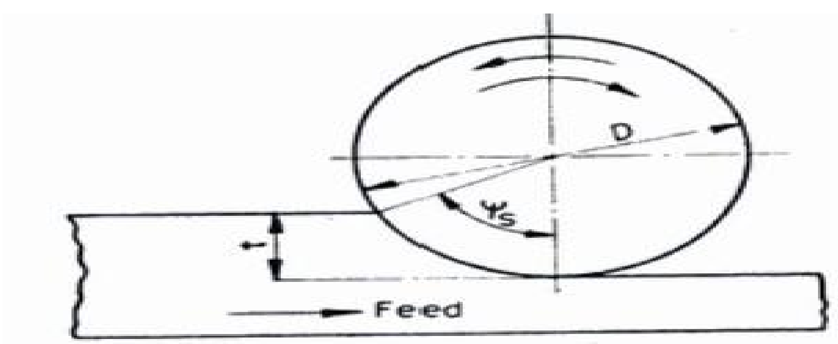
u= number of teeth of cutter

N= R.P.M of cutter

Cutting Forces in End Milling



Design calculations



For milling purpose w/p material is stainless steel(304)

All values are taken as per ANSI standards design for milling cutter as the cutter material to be taken as Highspeed steel;(HSS)

Tool diameter= 20mm

Values for H.S.S.:

1. Cutting speed, V_s = 18 m/min
2. Assumption values [15-19] m/min
3. Feed per tooth, (S_z) = 0.05mm
4. Assumption values =(0.02-0.08)mm
5. Depth of cut (t), (0.5-1) =1mm
6. Width of cut(b) = ½ tool diameter
7. Chip thickness, $a_s = 11.46/\Psi_s * S_z * t/D$

Where Ψ_s = angle of contact with the work piece = 45^0

$a_s = 11.46/45 * 0.05 * 1/20 = 6.36 * 10^{-3}$
= 0.00636 mm

Calculation of tangential forces:
Fz = 6120 N/V.

Where N = power at the spindle = N*U*K*k_r*Q

U = unit power KW/cm^3/min
K_1 = correction factor for materials and hardness
K_2 = correction factor for radial rake angle

From standard values according to chip thickness the values of U can be considered
For chip thickness of 6.36*10^{-3} and BHN and work material to be taken as a stainless steel

U = 74*10^{-3}*K_1*K_2
For K_1= of BHN = 200 K_1 = 1.3
K_2 = rake angle for stainless steelshould be $8^0 - 10^0$
from table K_2=1
U= 74.3*10^{-3}
Where Q= metal removal rate
= b*t*s_m/1000
=10*1*S_z*Z*n/1000

Where Z= teeth no=3
N= spindle speed = V_c*1000/π*D=18*1000/π*20 rpm
=10*1*0.05*3*18*1000/π*20
=429 cm^3/min

Tangential force
Ft= 6120*429*74.3/18
= 10837.398kgf = 106314.87N
For end milling
Fx=0.15 to 0.25p_z
Fr= 0.45 to 0.55p_z
Fx = Axial component force
Fr= radial component force
Consider as Fx=0.2
Fr=0.5

Fx= 0.2*106318.87 = 21262.97N
Fr=0.5*106314.87 = 53157.4N

For plain carbon steels:

Cutting speed=36m/min
Feed for tooth=(S_z)=0.10mm
Depth of cut=1mm
As=chip thickness
=11.46/Ψs*Sz*t/D
=11.46/45*0.1*1/20=1.2733*10^{-3}
=0.427mm
=0.001273mm
For tangential force (p_z)
Pz=6120N/U_s
N=U*K_n*K_r*Q
For chip thickness of 1.2733*10-3 the value of 'U' can be taken as
U= 80*10-3 KW/cm3/min
For K_n= K_1 =1.3
K_z= /π*20=572.95rpm
Q=10*1*0.1*3*572.95/1000
=1.71885Cm3/min

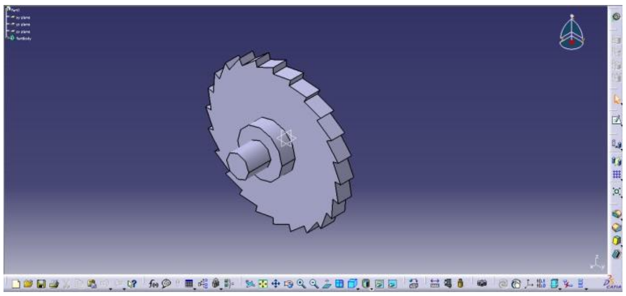
TangentialForce=
(6120*1.71885*80.3*$10^{-3)}$/36
=844.704/36
=23.4640kgf= 230.14N

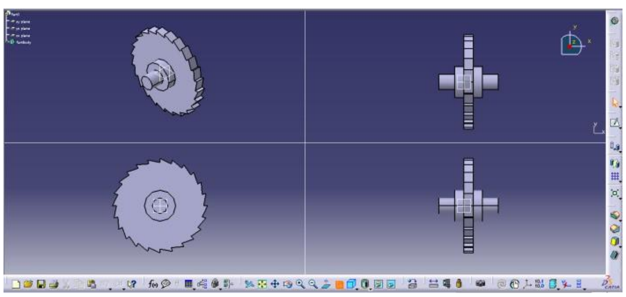
Fx = 230.14*0.2 = 46.028N

Fr = 230.15*0.5 = 115.07N

MODELING OF PLAIN MILLING CUTTER USING CATIA

CATIA V5 is used to model the plain milling cutter and various views are presented in





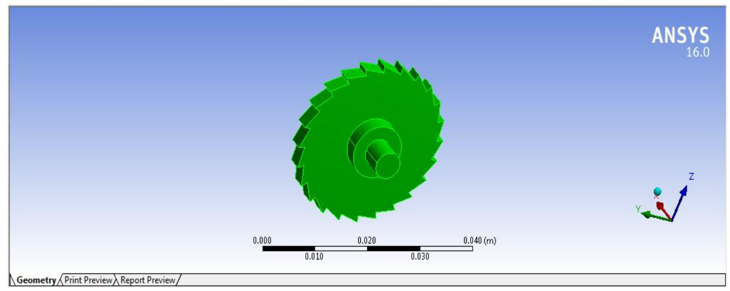
ANSYS ANALYSIS ON MILLING CUTTER:

STATIC ANALYSIS ON MILLING CUTTER

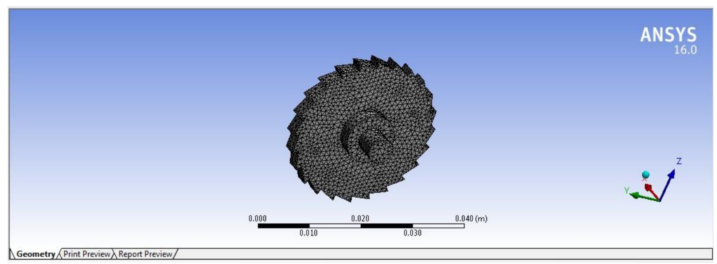
properties

Material	Density (kg/m^3)	Young's modulus (mpa)	Poisson's ratio
High speed steel	8000	200000	0.3
Plain carbon	7600	207000	0.3
steel			

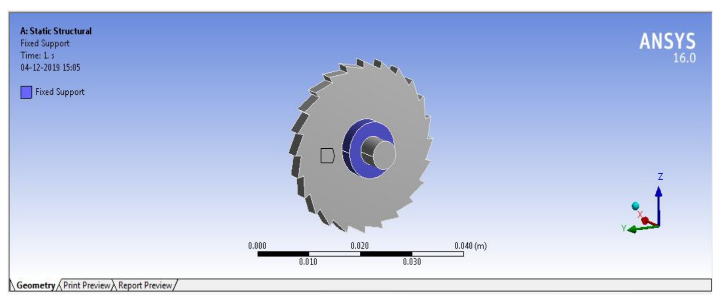
Table - 1



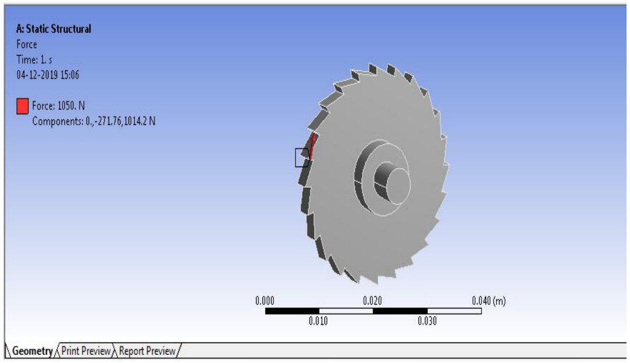
mesh



Fixed Support



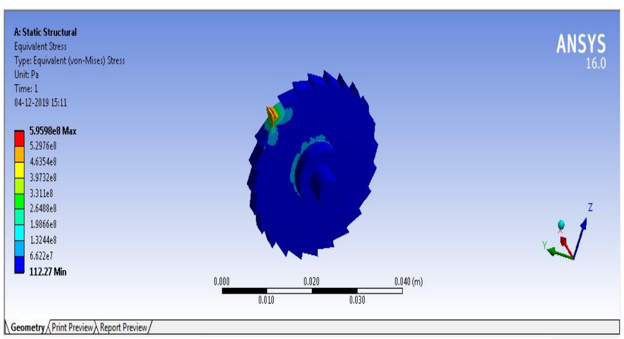
load: force =1014.2N



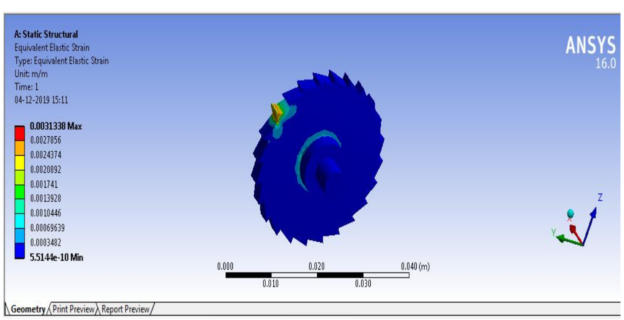
RESULTS

plain carbon steel

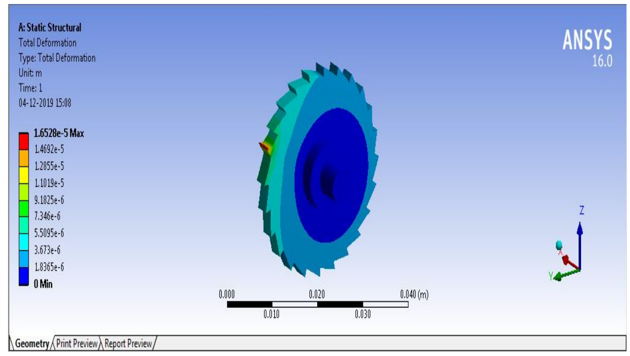
Stress



Strain



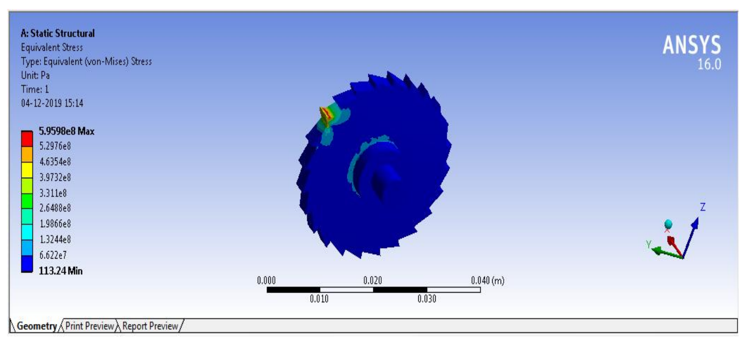
Deformation



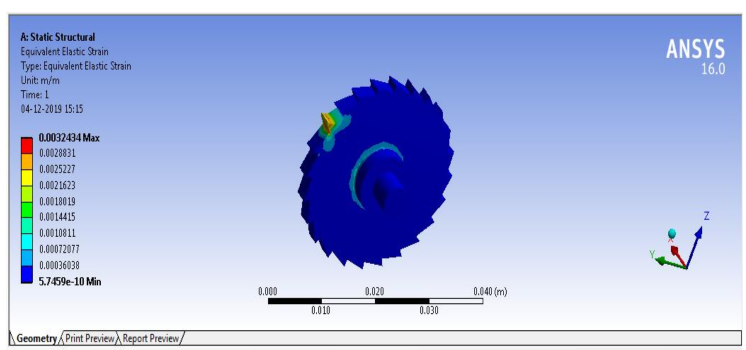
RESULTS

High Speed Steel

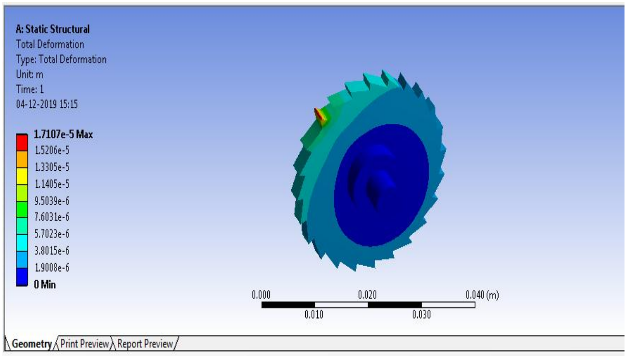
Stress



Strain



Deformation



Material	Stress (mpa)	Strain	Deformation (mm)
High speed carbon	$5.9598e^{8}$	0.003243	$1.7101e^{-5}$
Plain carbon steel	$5.9698e^{8}$	0.003133	$1.6528e^{-5}$

Table – 2

RESULTS AND DISCUSSIONS

1. The Tool Diameter has taken 20mm, the tangential force 106314.87 is in safe design as per the experimental tool design for HSS
2. For plain carbon steel the cutting speed is taken 36 m/min the tangential force is 230.14; hence the design is safe.
3. Static structural analysis is carried out on milling cutter teeth 1014.2 N load with all two materials in analysis workbench
4. Maximum stress, deformation, maximum strain and weight are noted and tabulated.
5. From the tables it is concluded that the plain carbon steel material is showing efficient results because of good strength to weight ratio compare to other materials.
6. Hence plain carbon steel is preferable among the two applied materials. It can be used for future Purpose.

CONCLUSION

1. Modeling and analysis of milling cutter is done
2. Modeling of milling cutter is done in CATIA v5 design software by using various commands
3. The CATIA part file is converted into IGS file and imported to ANSYS workbench.
4. Analysis is performed on two different materials one generally used high speed steel and plain carbon steel.

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