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Optimizing Feed and Radial Forces in CNC Machining of P-20, Tool Steel through Taguchi's Parameter Design Approach

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ABSTRACT

The objective of the paper is to obtain an optimal setting of CNC machining process parameters, cutting speed, feed rate resulting in optimal values of the feed and radial forces while machining P – 20 tool steel with TiN coated tungsten carbide inserts. The effects of the selected process parameters on the chosen characteristics and the subsequent optimal settings of the parameters have been accomplished using Taguchi's parameter design approach.

The process parameters considered are – Cutting speed 3000rpm, 2500rpm and 2000rpm. Feed rate 200mm/min, 300mm/min and 400mm/min and depth of cut is 0.2mm, 0.3mm and 0.4mm.The effect of these parameters on the feed force, radial force are considered for analysis.

The analysis of the results shows that the optimal settings for low values of feed and radial forces are high cutting speed, low feed rate and depth of cut.

The thrust force and feed force are also taken experimentally using dynamometer for above Cutting speeds, feed rate and depth of cut. The optimal values for speed, feed rate and depth of cut are taken using Taguchi technique in Minitab software.

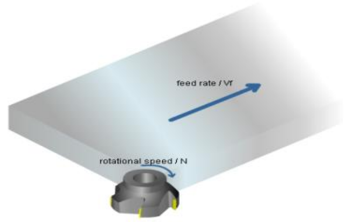
Process used in this project is milling process. Machine selected is Vertical milling center. Machine model selected is BFW Agni 45. Modeling is done in Pro/Engineer and analysis is done in ANSYS.

INTRODUCTION TO MILLING

Milling is the process of cutting away material by feeding a work piece past a rotating multiple tooth cutter. The cutting action of the many teeth around the milling cutter provides a fast method of machining. The machined surface may be flat, angular, or curved. The surface may also be milled to any combination of shapes. The machine for holding the work piece, rotating the cutter, and feeding it is known as the Milling machine.

CUTTING AND FEED MOVEMENTS

Milling is a forming operation whereby chips are removed using a cutting tool known as a "milling cutter". This has several cutting edges laid out around its axis of rotation, and is subjected both to a rotational movement and a feed motion. This type of operation is carried out on what is called a milling machine.



CUTTING PARAMETERS

A milling operation is characterised by the following parameters:

a_p: Axial engagement of the tool, also known as the axial pass depth in mm.
a_e: Radial engagement of the tool in mm.
N: Rotational speed in rev min^{-1}.
v_c: Cutting speed in m min^{-1}.
f_z: Feed per tooth in mm $tooth^{-1}$.
v_f: Feed rate in mm min^{-1}.
Q: Material removal rate in cm^3 min^{-1}

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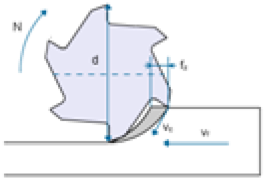
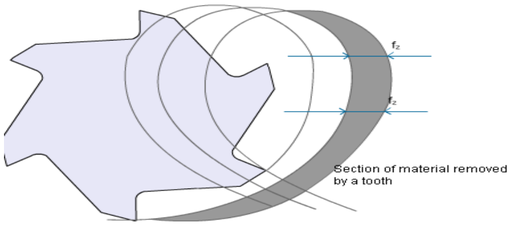


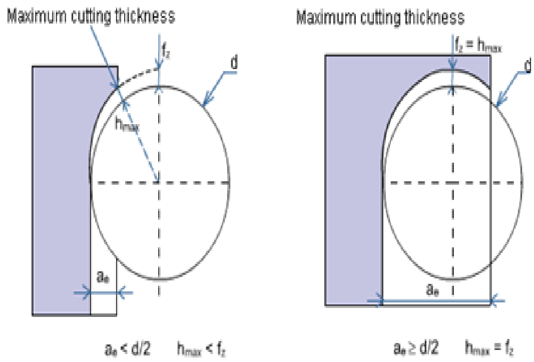
TOOL PATH

The trajectory of a milling cutter tooth through the material follows a cycloidal curve.



CHIP THICKNESS

It is important to take into account the maximum chip thickness (h_{max}). Indeed, this may be less than the feed per tooth (f_z) and may produce a too small chip thickness (minimum chip size) which leads to a cutting fault.



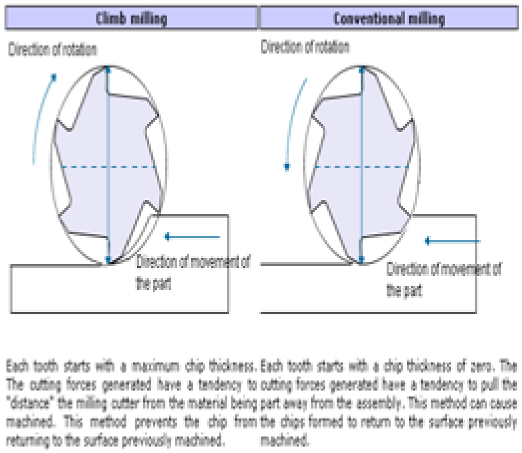
Remark: the minimum acceptable chip thickness cannot be defined as a general rule: it is a function of the material being machined, the type of milling cutter used, the quality of the sharpening and the geometry of the tool.

DIRECTION OF ROTATION

The way the milling cutter works has a significant impact on machining quality. There are two methods:

- Climb milling
- Conventional milling.

In most cases, it is preferable to use climb mill



POWER

The cutting power, P_c is a factor that it is important to determine, especially for the rough machining of aluminium. It makes it possible:

To choose a machine with a power output suited to the work being done. To achieve cutting conditions that allow the power of the machine to be used to obtain the best possible material removal rate, while taking into account the tool's mechanical resistance.

When choosing a machine, one must also take into account the admissible torque for large diameter tools, as well as the available speed and feed ranges.

These factors will enable us to choose the machine with which it will be possible to carry out the milling operation in the most effective way possible.

Power	$P_c = \frac{K \times Q}{1000}$	Q: Material removal rate in $cm^3\ min^{-1}$ K: coefficient - specific cutting power in W $cm^{-3}\ min^{-1}$ P_c: cutting power in kW
Torque	$C = \frac{P_c}{\varpi}$ with $\varpi = \frac{2\pi N}{60}$	ω: angular speed in rad s^{-1} C: torque in N m N: rotational speed in rev min^{-1}

CUTTING ANGLES

The geometric definition of a milling cutter involves a large number of angles. For an insert cutter, the main angles are:

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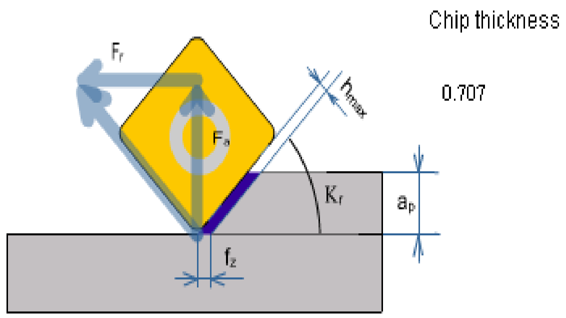
- the tool cutting edge angle. Kr
- the radial angle. Γf
- the axial angle. Γp
- the clearance angle. A

The angles are given for inserts fitted to the body of the tool, because the geometry of the insert must always be added to that of the milling cutter body.

(The symbols and terminologies for the tool's parts are defined by the ISO 3002/1 and NF E 66-502 standards). Recommendations for cylindrical cutters with detachable carbide inserts, for use with light alloys.

Clearance angle α	Tool cutting edge angle K_r	Radial angle γ_f	Axial angle γ_p
8° to 10°	45° to 75°	+15°	+15°

TOOL CUTTING EDGE ANGLE



Influence on chip thickness: $h_{max} = f_z \times \sin K_r$
$K_r = 90°$ to cut a straight shoulder
$30° < K_r < 75°$ for surfacing
Usually $K_r = 45°$ (reduction in chip thickness, predominant axial force F_a and attenuation of vibrations)

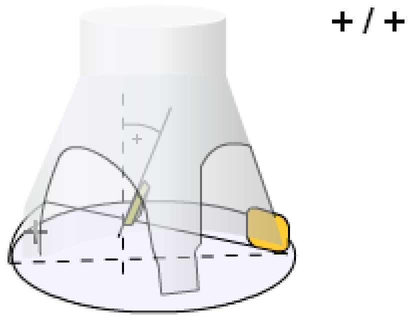
INFLUENCE ON FORCES

When the angle of attack, K_r increases:

- The radial load, F_r increases proportionally.
- And a_p stays the same, the contact area (between the part and the insert) is reduced.
- And the feed rate stays the same, chip thickness increases.

RADIAL AND AXIAL ANGLES

Combination of the axial cutting angle and the radial cutting angle

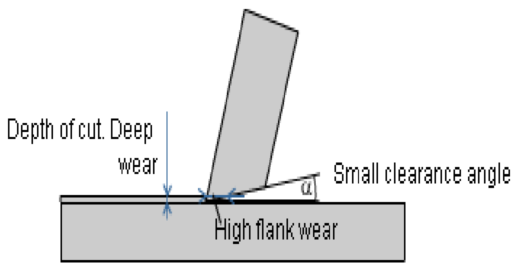


Axial/radial combination	+/-	+/+	-/-
advantages	Chip formed and removed effectively. Good insert resistance	Chip formed effectively. Axial removal	Very good insert resistance
disadvantages		Low cutting edge resistance	Considerable forces Chip removal
Materials machined	All materials: Versatile	Light alloys	Cast iron (use of inserts made from a brittle grade of material)

* The combinations +/- and +/+ are the most commonly used.

CLEARANCE ANGLE

The clearance angle creates a space between the tool and the part.
the clearance angle prevents friction between the flank of the tool and the part.
the clearance angle favours the cutting edge sharpness required for the milling of aluminium alloys.



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INSERT GEOMETRY

In general, carbide manufacturers offer inserts that are specifically designed for the cutting of aluminium: a very positive cutting angle, with high sharpness (sharp edge).

The shape and dimensions of the inserts are coded according to ISO 1832-1991 standard.

LITERATURE SURVEY

PAPER 1 - Modeling of the Influence of Cutting Parameters on the Surface Roughness, Tool Wear and Cutting Force in Face Milling in Off-Line Process Control by Dražen Bajić* – Luka Celent – Sonja Jozić, University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Croatia

ABSTRACT

Off-line process control improves process efficiency. This paper examines the influence of three cutting parameters on surface roughness, tool wear and cutting force components in face milling as part of the off-line process control. The experiments were carried out in order to define a model for process planning. Cutting speed, feed per tooth and depth of cut were taken as influential factors. Two modeling methodologies, namely regression analysis and neural networks have been applied to experimentally determined data. Results obtained by the models have been compared. Both models have a relative prediction error below 10%. The research has shown that when the training dataset is small neural network modeling methodologies are comparable with regression analysis methodology and can even offer better results, in which case an average relative error of 3.35%. Advantages of off-line process control which utilizes process models by using these two modeling methodologies are explained in theory.

PAPER 2 - OPTIMIZATION OF SURFACE ROUGHNESS IN FACE TURNING OPERATION IN MACHINING OF EN-8 by K. Adarsh Kumar, Ch.Ratnam, BSN Murthy, B.Satish Ben, K. Raghu Ram Mohan Reddy

ABSTRACT

Surface finish is one of the prime requirements of customers for machined parts. The purpose of this research paper is focused on the analysis of optimum cutting conditions to get lowest surface roughness in facing by regression analysis. This present paper presents an experimental study to investigate the effects of cutting parameters like spindle speed, feed and depth of cut on surface finish on EN-8. A multiple regression analysis (RA) using analysis of variance is conducted to determine the performance of experimental measurements and to it shows the effect of cutting parameters on the surface roughness. Multiple regression modeling was performed to predict the surface roughness by using machining parameters. The investigation of influence of cutting conditions in facing operation of EN-8 in this paper. Machining was done using cemented carbide insert. The objective was to establish correlation between cutting speed, feed rate and depth of cut and optimize the turning conditions based on surface roughness. These correlations are obtained by multiple regression analysis (RA).

PAPER 3 - Effect of machining conditions on MRR and surface roughness during CNC Turning of different Materials Using TiN Coated Cutting Tools – A Taguchi approach by H. K. Dave, L. S. Patel, H. K. Raval

ABSTRACT

This paper presents on experimental investigation of the machining characteristics of different grades of EN materials in CNC turning process using TiN coated cutting tools. In machining operation, the quality of surface finish is an important requirement for many

ISSN No: 2348-4845
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turned work pieces. Thus, the choice of optimized cutting parameters is very important for controlling the required surface quality. The purpose of this research paper is focused on the analysis of optimum cutting conditions to get the lowest surface roughness and maximum material removal rate in CNC turning of different grades of EN materials by Taguchi method.

Optimal cutting parameters for each performance measure were obtained employing Taguchi techniques.

The orthogonal array, signal to noise ratio and analysis of variance were employed to study the performance characteristics in dry turning operation. ANOVA has shown that the depth of cut has significant role to play in producing higher MRR and insert has significant role to play for producing lower surface roughness. Thus, it is possible to increase machine utilization and decrease production cost in an automated manufacturing environment.

PAPER 4 - Optimization of surface roughness in CNC end milling using response surface methodology and genetic algorithm by B. Sidda Reddy, J. Suresh Kumar, and K. Vijaya Kumar Reddy

ABSTRACT

Pre-hardened steel (P20) is a widely used material in the production of moulds/dies due to less wear resistance and used for large components. In this study, minimization of surface roughness has been investigated by integrating design of experiment method, Response surface methodology (RSM) and genetic algorithm. To achieve the minimum surface roughness optimal conditions are determined. The experiments were conducted using Taguchi's L50 orthogonal array in the design of experiments (DOE) by considering the machining parameters such as Nose radius (R), Cutting speed (V), feed (f), axial depth of cut (d) and radial depth of cut(rd). A predictive response surface model for surface roughness is developed using RSM. The response surface (RS) model is interfaced with the genetic algorithm (GA) to find the optimum machining parameter values.

PAPER 5 - PREDICTION OF SURFACE ROUGHNESS IN END MILLING WITH GENE EXPRESSION PROGRAMMING by Yang Yang, Xinyu Li, Ping Jiang, Liping Zhang

ABSTRACT

Surface roughness has a great influence on the functional properties of the product. Finding the rules that how process factors and environment factors affect the values of surface roughness will help to set the process parameters of the future and then improve production quality and efficiency. Since surface roughness is impacted by different machining parameters and the inherent uncertainties in the machining process, how to predict the surface roughness becomes a challengeable problem for the researchers and engineers. In this paper, a method based on gene expression programming (GEP) has been proposed to construct the prediction model of surface roughness. GEP combines the advantages of the genetic algorithm (GA) and genetic programming (GP). By considering GEP as a very successful technique for function mining and formula found, it should be suitable to solve the above problem. On the basis of defining a GEP environment for the problem and improving the method of creating constant, the explicit prediction model of surface roughness can been constructed. To verify the feasibility and performance of the proposed approach, experimental studies conducted to compare this approach with some previous works are presented. The experimental results show that the proposed approach has achieved satisfactory improvement and obtained good results for several widespread studied problems.

MODELING OF CUTTER AND WORKPIECE ASSEMBLY

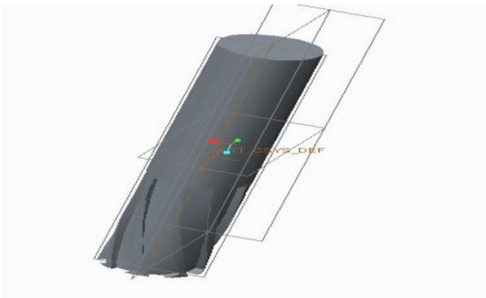


Fig – Tool drawn in creo

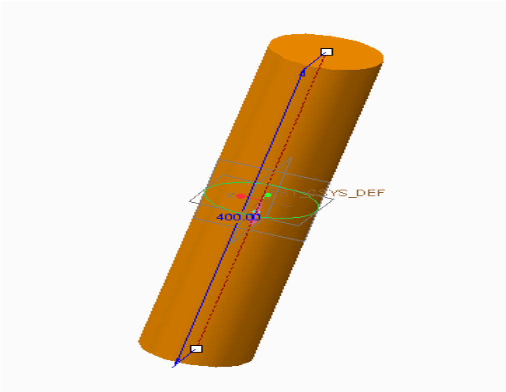


Fig – Extrude operation

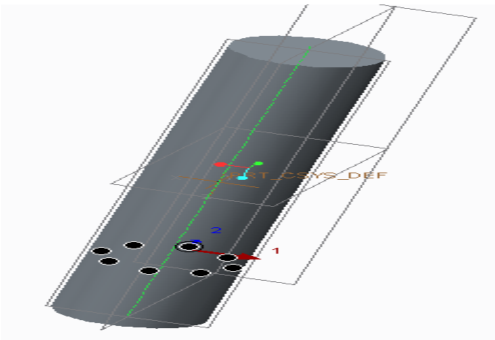


Fig – pattern operation

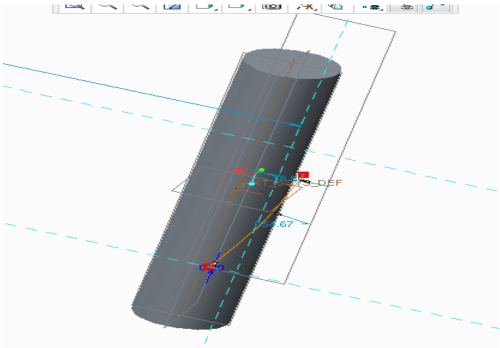


Fig – Warp operation

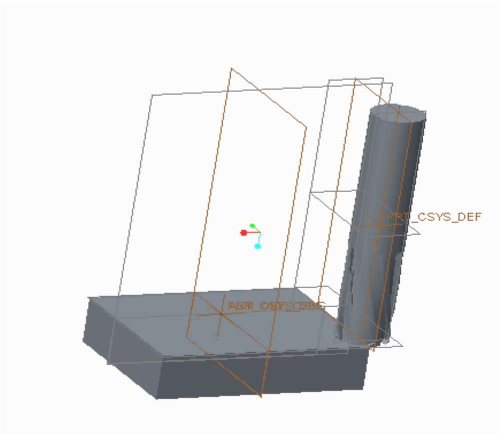


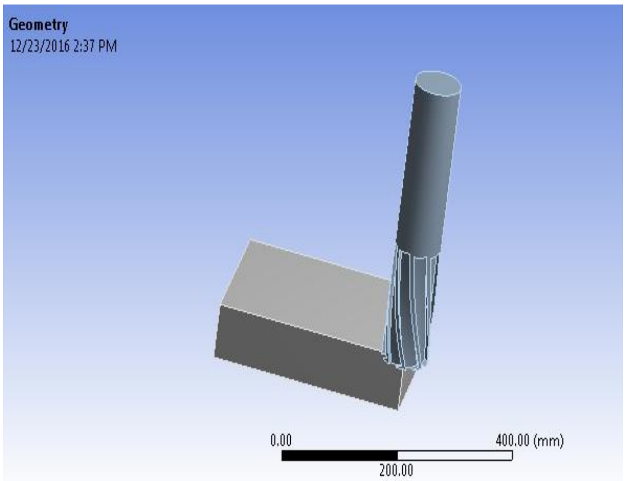
Fig –assembly of cutter and workpiece

ANALYSIS OF CUTTING TOOL AND WORKPIECE ASSEMBLY

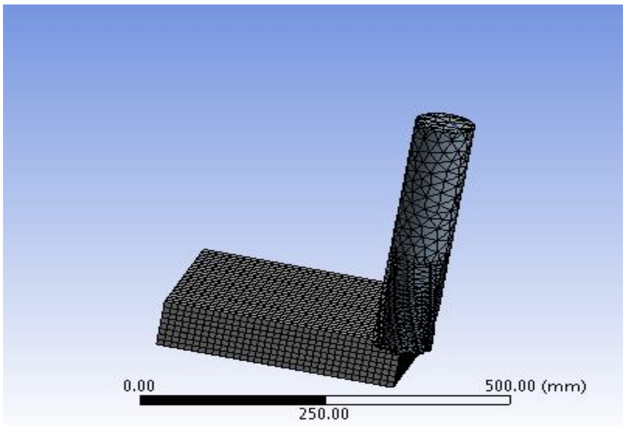
STRUCTURAL ANALYSIS

P20 TOOL STEEL

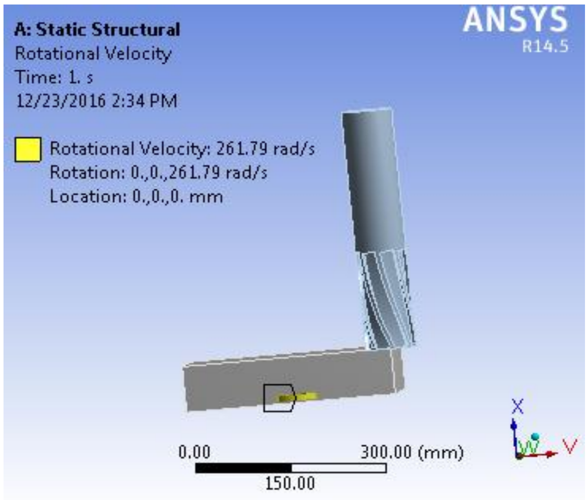
IMPORTED MODEL



MESHED MODEL



ROTATIONAL VELOCITY



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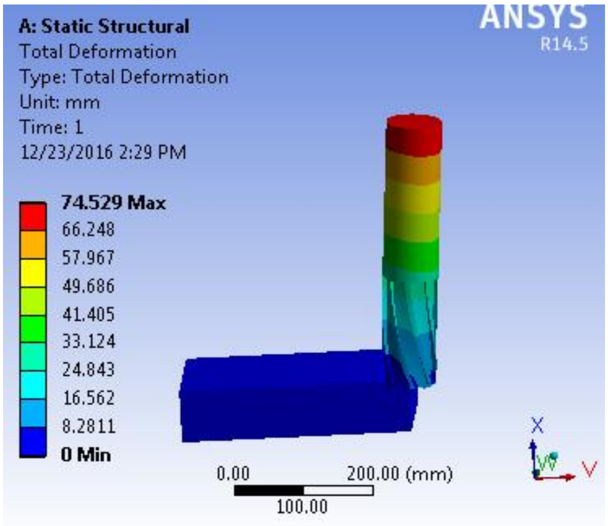
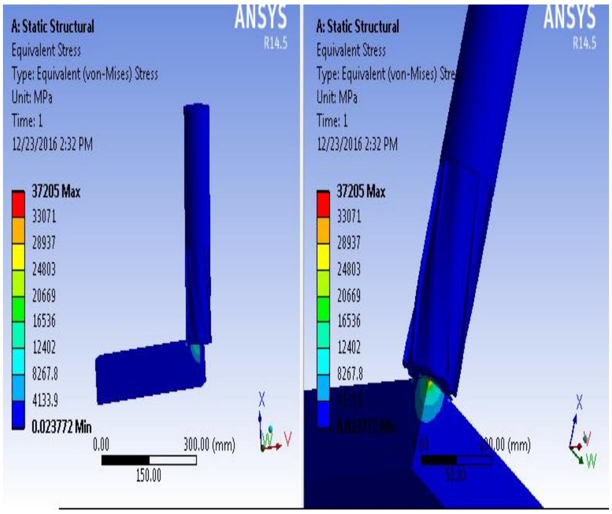
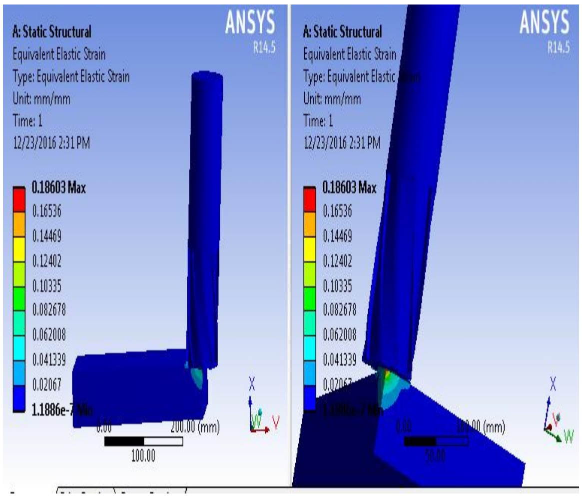
TOOL SPEED - 3000 RPM
TOTAL DEFORMATION



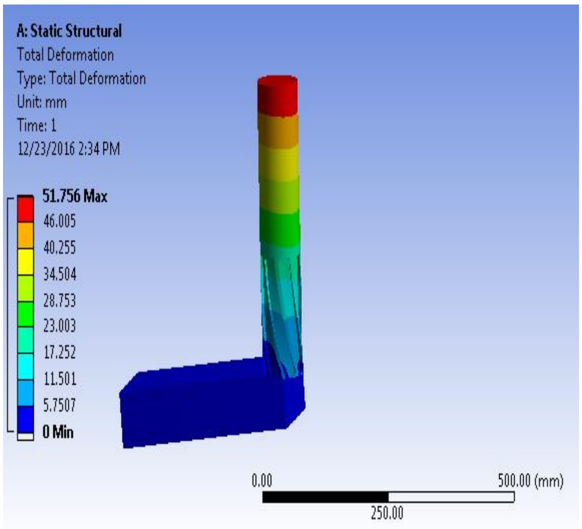
STRESS



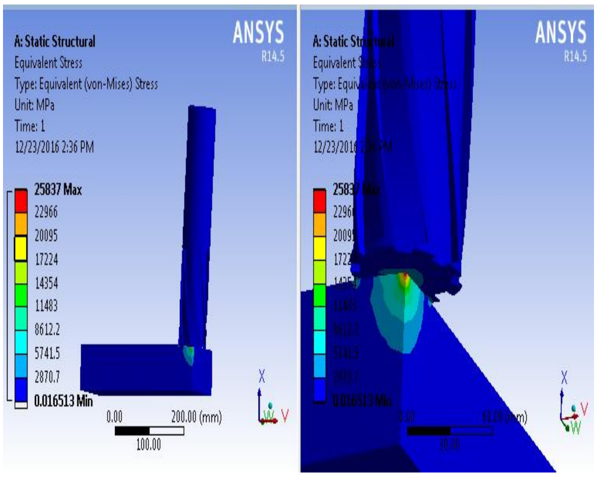
STRAIN



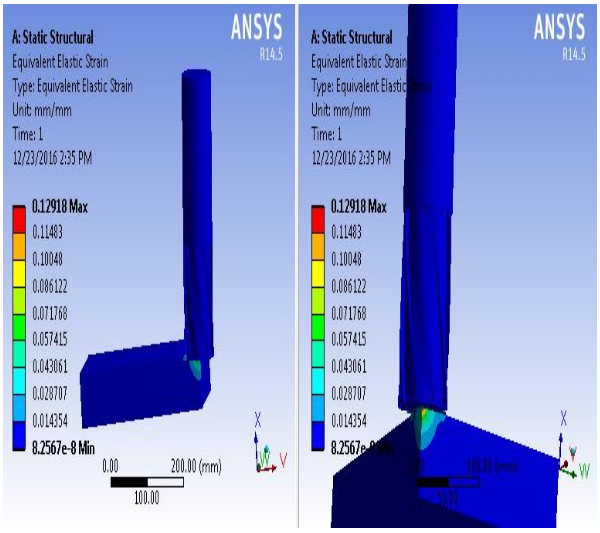
TOOL SPEED - 2500 RPM
TOTAL DEFORMATION



STRESS



STRAIN



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TOOL SPEED - 2000 RPM

TOTAL DEFORMATION

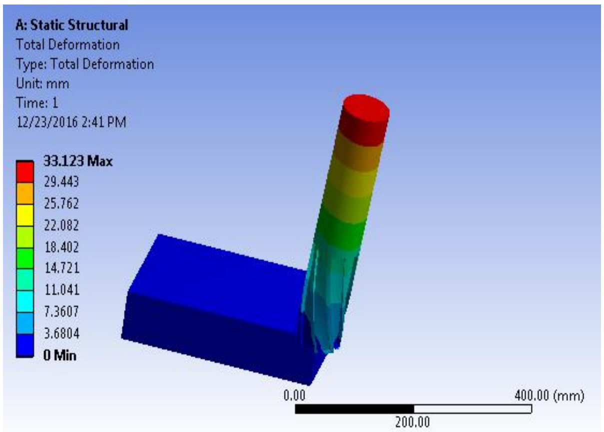


Fig – Total Deformation at 2000 rpm

STRESS

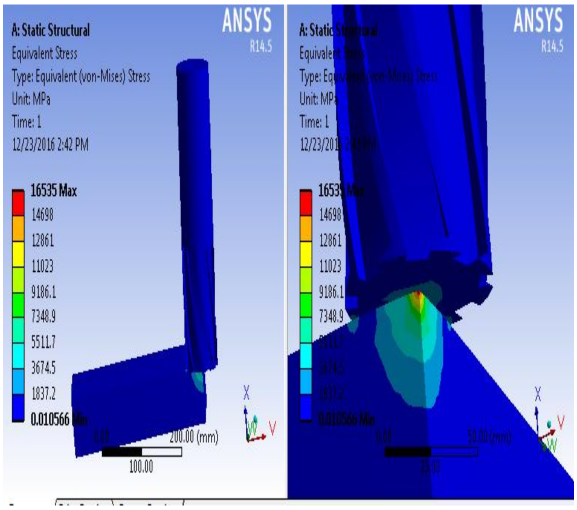


Fig – Stress at 2000 rpm

STRAIN

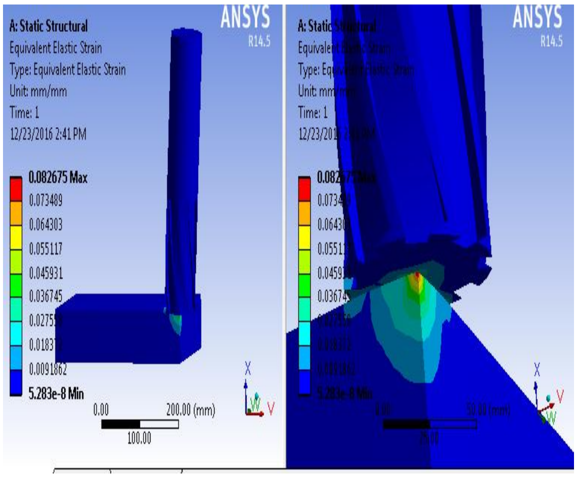
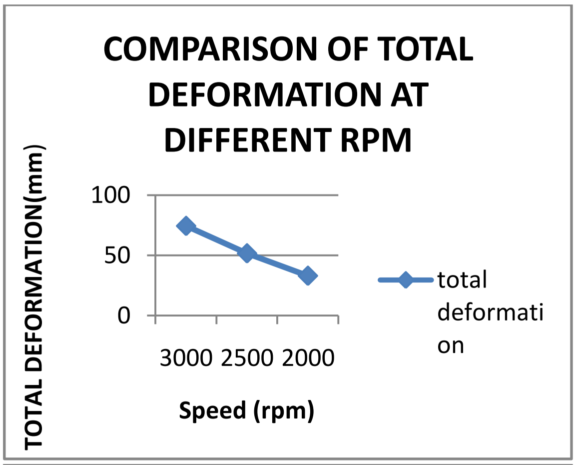


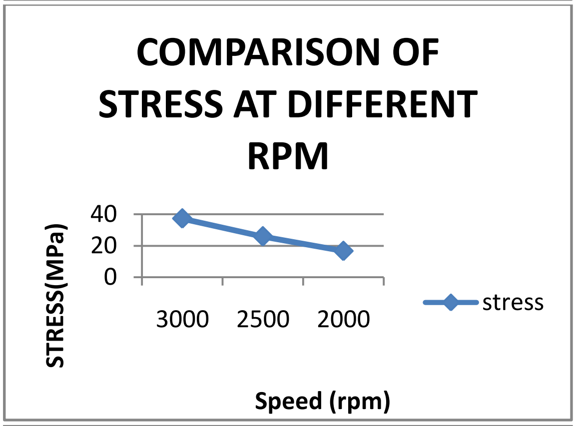
Fig – Strain at 2000 rpm

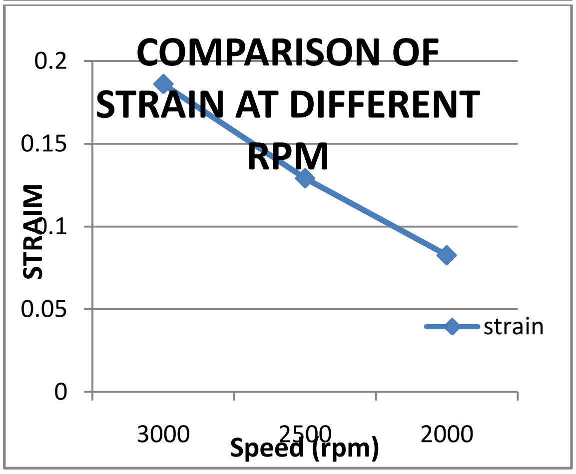
RESULTS TABLE

Speed (rpm)	3000	2500	2000
Total deformation (mm)	74.529	51.756	33.123
Stress (MPa)	37.205	25.837	16.535
Strain	0.18603	0.12918	0.082675

GRAPHS







From the analysis results, the analyzed stress values are less than its yield stress value. So using these process parameters Spindle Speed, feed rate and depth of cut for machining P20 Tool Steel are suitable.

CONCLUSION

P20 Tool Steel is considered for milling process which is used in die casting process and the influence of cutting parameters spindle speed, feed rate and depth of cut on thrust force and torque for the material is done theoretically using calculations and experimentally using Taguchi technique.

The parameters considered are cutting speed, feed rate and depth of cut. The cutting speeds are 3000rpm, 2500rpm and 2000rpm. The feed rates are 200mm/min, 300mm/min and 400mm/min and depth of cut is 0.2mm. From the analysis results, the displacement and stress values are less for all speeds. The stress values are very less compared with its yield stress value. So we can conclude that using P20 tool steel for die casting process is suitable.

Feed force and radial forces are taken experimentally using dynamometer by considering parameters cutting speed, feed rate and depth of cut. The optimal values for speed, feed rate and depth of cut are taken using Taguchi technique.

The optimal settings of various process parameters for CNC machined parts to yield optimal forces are: Speed – 2000rpm, Feed rate – 400mm/min, Depth of cut – 0.4mm when thrust force is taken (i.e.) feed force and when torque (i.e.) radial force is taken the optimal values are Speed – 2500rpm, Feed rate – 200mm/min, Depth of cut – 0.2mm.

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