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Optimization of the Drilling Cutter Performance by using Ansys

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Abstract— The purpose of this work is to predict the optimum Cutting velocity of the Tungsten drilling cutter and optimum feed of the Al-1100 work piece with the help of surface optimization tool of ANSYS. This study leads to the conclusion that the Surface optimization tool performed well to predict the results of high performance. Also, On the basis of creating a mathematical model of Drilling Cutter, we generate the 3-D model of the drilling cutter in CATIA 5.1 for Simulation with Finite Element Analysis to determine the effect of Total Deformation, Equivalent Stress and Equivalent Elastic Strain on the Drilling Cutter due to the constant Cutting velocity of the tool and constant feed of the work piece.

Keywords: Surface Optimization; FEM; Cutting Velocity; Feed Rate; Drilling Cutter

I. INTRODUCTION

Drilling is the method of making holes in a work piece with metal cutting tools. Drilling is associated with machining operations such as drill, countersinking, boring and drilling. The principal rotary motion is common to all these processes, combined with linear progress. There is a clear distinction between drilling short and deep holes. The drilling process can in some respects be compared with turning and milling, but the requirements for chip breaking and chip removal are necessary for drilling. Machining is limited by the size of the hole, the greater the depth of the hole, the more difficult it is to control the process and remove chips. Short holes occur frequently on many components and high material removal rate is a growing priority along with quality and reliability.

II. PRINCIPLES OF DRILLING

The wide variety of drilling conditions at field level makes it difficult to develop general operating principles to achieve maximum drilling performance. Field experience is usually the basis for operations in a given area, but testing is often too expensive and experience too late. Therefore, a method is needed to determine the optimal drilling techniques and parameters for a given drilling state, with minimum engineering and drilling experience.

Drilling parameters or variables, both are related to rotary drilling were analyzed and divided into two groups as independent and dependent parameters. Independent variables are those that can be directly controlled by the drilling rig operator, and dependent variables are those that represent the response of the drilling system to the drilling operation.

There are, of course, many factors other than those discussed here that effect drilling efficiency and footage cost. These include factors such as the hardness of the formation, the abrasion of the formation and the depth of the well. As these items cannot be conveniently controlled, their influence on costs must simply be accepted.

III. HISTORY OF DRILLING

Kug et al. [1] developed a cutting model using the thermoplastic-visco-plastic method using the finite element method (MEF) to analyze the mechanics of the orthogonal cutting process in a stable state. The model was able to manage the chip geometry and the tool contact length. Coupling with thermal effects was also considered. In the calculation of temperature distributions, the "against the wind" scheme was used to eliminate the spurious oscillations that occur in the solution and, therefore, it was possible to assume the metal cutting at highest speed. To validate the cutting model, orthogonal cutting test are performed for 0.2% carbon steel. The forces of the instrument were measured and the results were compared with the results of the FEM analysis.

Chandrasekharan et al. [2] developed models to predict thrust and torsion forces in different cutting regions in a drill. The mechanistic approach used to develop these models uses process geometry that was independent of the material of the element. The models were calibrated for a specific material using the consolidated relationship between chip loading and shear forces, modified to take advantage of the geometric features of the drilling point. The sharp model predictions coincided well with the experimental data of both materials, the proposed chisel model for metals was in agreement with the experimental data.

Chandrasekharan et al. [3] developed a model for predicting forces for any well point geometry. Sharp lips were divided into elements, and elemental forces were determined by the basic oblique cut model.

The model did not require calibration experiments for each point geometry. In this case, the tapered drill was used to determine the model coefficient for the combination of tool and work piece material, as well as for different drill geometry.

Bergstrom et al. [4] developed a model for predicting torque and drilling thrust using a minimum cutting energy method to predict the chip's flow angle. The model was tested experimentally and it was shown that the minimum cutting energy model predicted thrust and torque with greater precision than the most commonly used Stabler rule.

Min et al. [5] introduced a finite element model method for creating two-dimensional orthogonal burr or mills and confirmed this with experimental observations. A detailed and in-depth review of the spot formation process was carried out. This information was then used to build the analytical model and led to the development of a three-dimensional model of finite burr elements. Using the model as a model, problems with simulation of burr or mills formation were simulated that were not physically investigated, and the results were used to control process planning, which led to reduced burr formation.

Guo et al. [6] developed an explicit EMF-thermoelastic-visco-plastic model to predict the effects of orthogonal sequential cuts in the mechanical state and the cutting mechanisms in a mechanized layer. It has been shown that the distribution of residual stresses has changed significantly and the cutting mechanisms have changed slightly in the sequential sections. A method for pre-compression for the compression of a machined surface has been proposed by planning the thickness of the cut without cutting. An assessment was made of the effects of shear forces, shear temperatures and clamping forces on the distribution of residual stresses.

Strenkowski et al. [7] developed a 3-D model for predicting tool forces. The approach consisted of coupling an orthogonal model of finite element cutting with a three-dimensional analytical model. The finite element model method was totally based on Euler's approach. Analytical model developed by Usui et al. [8]. It was used, in which a minimum energy approach was used to determine the direction of flow of the chip. Model developed by Usui [8] Data from perpendicular cutting test required to determine tool forces and chip flow angle. A finite element model was used to provide orthogonal cutting data for Usui [8]. With this approach, a three-dimensional exclusion prediction model was developed that does not require input measurement data. The machining experiments described correspond to the measured flux forces and angles measured and intended for the processing of AISI 1020 steel.

Strenkowski et al. [9] developed a finite element analytical technique to predict thrust force and torque in drilling with helical drill bits. The method was based on the re presentation of cutting forces along the cutting edges as a series of oblique cross-sections. In addition, an Euler's finite element model was used to calculate the cutting forces. A good agreement was found between the forces and torques provided and measured in the orthogonal and oblique section and in the drilling tests. Drilling tests were carried out on AISI 1020 for different tip diameters, spindle speed and feed speed.

Pirtini et al. [10] presented a new mathematical model based on the mechanics and dynamics of the drilling procedure to support cutting forces and good quality efforts. A new method of obtaining cutting factors derived from a sequence of relatively simple calibration tests has also been proposed. The model was able to simulate cutting forces for various cutting conditions during the process planning phase. In the Structural Dynamics module, the measured frequency response functions of the spindle and tool system were integrated into the model to obtain perforated hole profiles. Therefore, in addition to predicting forces, the new model enables the defination and visualization of 3D hole profiles and the appropriate selection of parameters in accordance with production limits and tolerances.

Bakkal et al. [11] studied the thrust force, torque and tool wear when drilling metallic glass material based on Zr (BMG). Fast speed BMG drilling generated by chip emissions, fast tool temperature and low tool wear. At low speed of the shaft, the BMG work material accumulates on the cutting edges of the edge and edge and can break the hole. In this test, the range of feed speed and feed speed was determined for efficient BMG drilling without harmful light chip emissions or the accumulation of state-of-the-art working material. Under the same drilling situation, the WC-Co instrument usually required less thrust and the same torque as the high speed steel tool. The progressive wear of the main cutting edges and the margins for BMG perforation was examined. The severe wear of the cutter was associated with the intense light output of the BMG chip. Without chip emission, drilling wear was visible but not severe.

Ming-Hung Hsu [12] predicted the dynamic features of the drilling procedure. To simulate the exercise, a pre-curved Bernoulli-Euler radius was used. The problem of the Eigen value of a pre-distorted rotating beam under axial load on an elastic basis was formulated numerically using the differential quadrature method (DQM). The effects of the number of sampling points, the rotation speed, the pre-torsion angle, the axial load and the stiffness of the elastic foundation at the calculated natural frequencies were also investigated. Numerical results show the importance and effectiveness of DQM in dealing with this kind of problem. The calculation times for DQM were shorter than for FEM. A flexible, variable length base was used to estimate the drilling process.

Dargnat et al. [13] studied a semi-analytical model for determining forces in the tool as well as heat fluxes and temperatures along the edge of the bit.

Leading edge and chisel edge included. He also took into account the elastic relaxation in the free surface with the edge sharpness, as well as an adequate modelling of the phenomena occurring in the edge of the chisel in relation to its geometry and to the kinetics of a drilling operation.

IV. MODELLING

According to the literature review, it is found that Finite Element Analysis (FEA) is a useful tool for simulation. By using FEA measure the Equivalent Stress, Equivalent Elastic Strain and Total Deflection when constant Cutting velocity acts on the drilling tool and constant feed given to the work piece. After that we are using the Surface Optimization tool to predict the performance of Tool under constant feed and constant cutting velocity.

The objective of present work is formulated and summary of these objectives are,

- To develop a mathematical model with the help of CATIA and Simulate the same model with the help of ANSYS.
- Finite Element Analysis with the help of ANSYS to find the Equivalent Stress, Equivalent Elastic Strain and Total Deflection due to forces.
- Developing a Surface optimization Model to find out the optimum cutting velocity and feed for particular tool and work piece material.

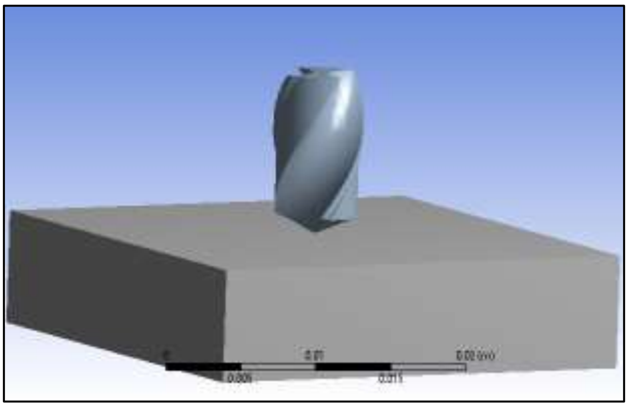


Fig. 1: After modelling in CATIA software existing assembly of Drilling Cutter with work piece

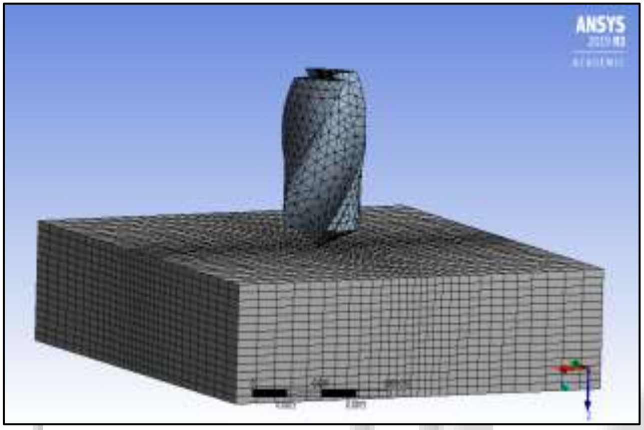


Fig. 2: After modelling in CATIA software, triangular type of meshing of Drilling Cutter is done in ANSYS software

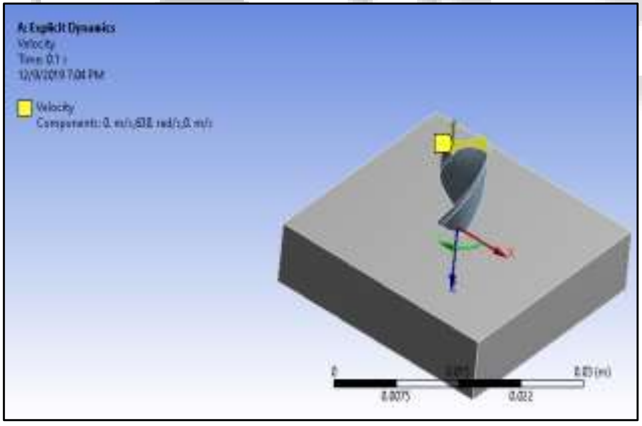


Fig. 3: Cutting Velocity given to the Drilling Cutter in Explicit Dynamic tool of ANSYS

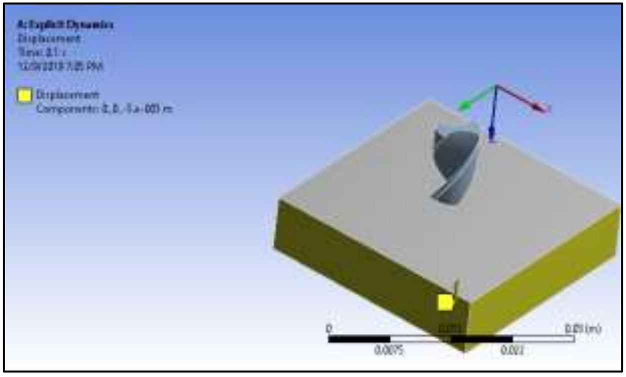


Fig. 4: Linear Displacement or Feed is given to the Work piece is done in Explicit Dynamic tool of ANSYS

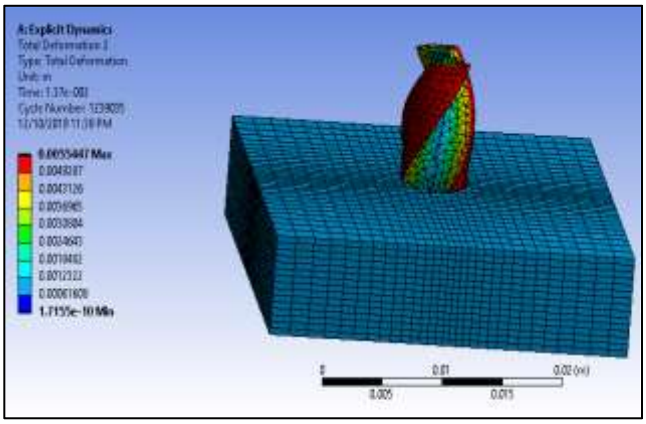


Fig. 5: By analysis in ANSYS software, total deformation developed in Drilling Cutter & work piece

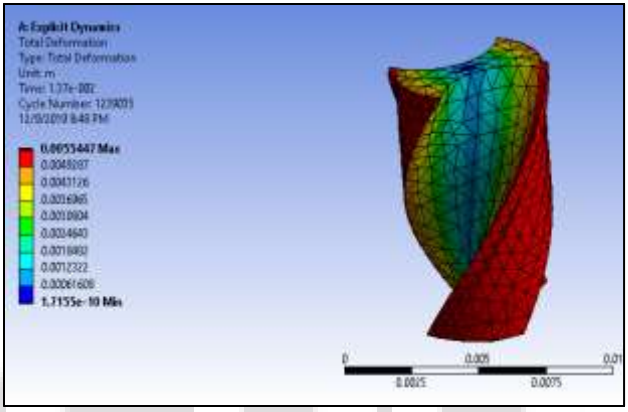


Fig. 6: By analysis in ANSYS software, total deformations developed in Drilling cutter

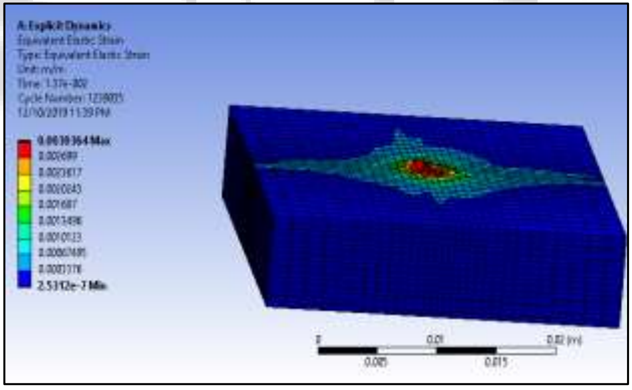


Fig. 7: By analysis in ANSYS software, Equivalent Elastic strain developed in work piece

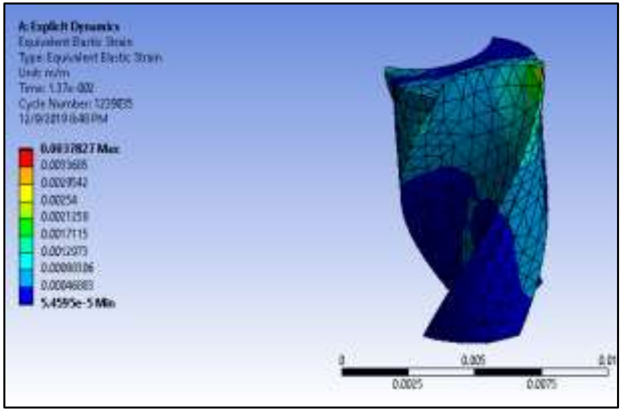


Fig. 8: By analysis in ANSYS software, Equivalent Elastic strain developed in Drilling Cutter

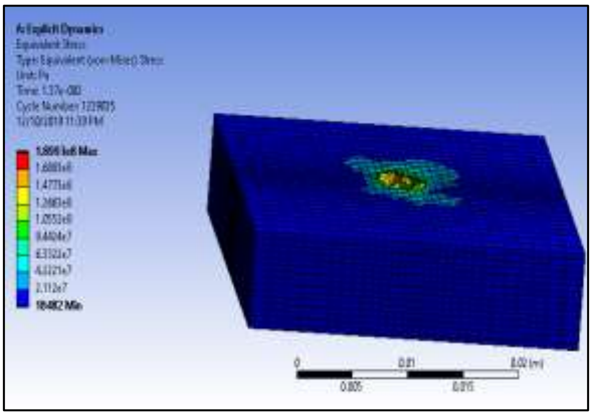


Fig. 9: By analysis in ANSYS software, Equivalent Elastic stress developed in work piece

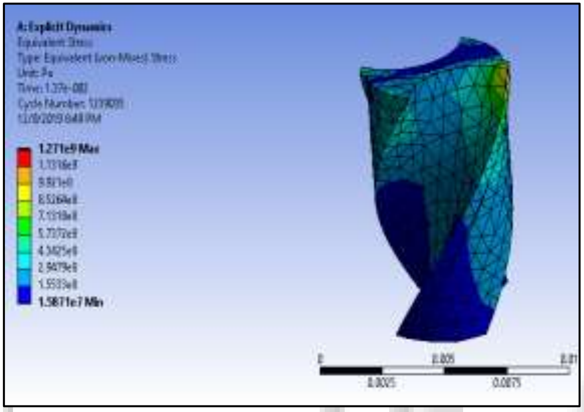


Fig. 10: By analysis in ANSYS software, Equivalent Elastic stress developed in Drilling Cutter

V. RESULTS

The response surface optimization was developed to help the engineers design systems that are efficient and less costly and to find out the optimum method to improve the performance of the design. Response surface optimization can be classified as a type of mathematical approach to finding out and select a best parameter magnitude out of probable parameter alternatives.

Response Surface Optimization methods known as mathematical programming techniques are basically a study or a part of Operations Research. This is a branch of mathematics that deals with scientific methods and techniques for optimum decision making with the aim of identification of the best solutions. DOE (Design of experiments) is one of the well-defined fields of operation research. This technique enables us to analyze the experimental data and generates the empirical models to get the most accurate response of the physical problem. Response surface modelling (RSM) are commonly used in engineering design to minimize the computational cost involved in the simulation.

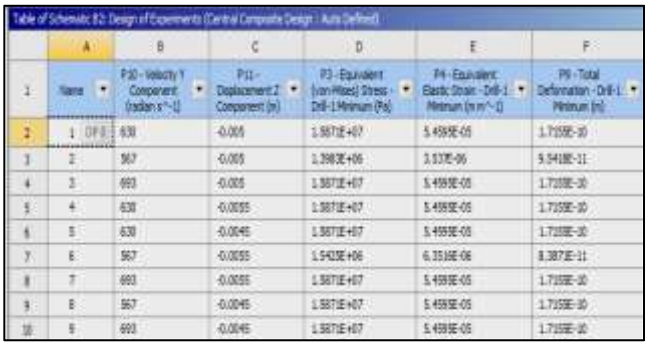


Table of Schematic B2: Design of Experiments (Central Composite Design : Auto Defined)

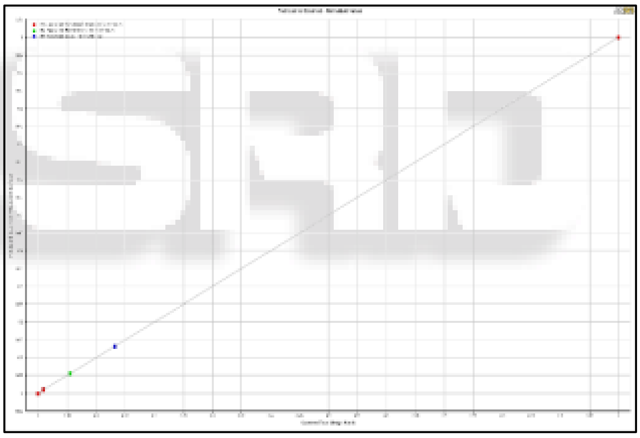
	A	B	C	D	E	F
1	Name	P10 - Velocity Y Component (radian s^-1)	P11 - Displacement Z Component (m)	P3 - Equivalent (von-Mises) Stress - Drill-1 Minimum (Pa)	P4 - Equivalent Elastic Strain - Drill-1 Minimum (m m^-1)	P9 - Total Deformation - Drill-1 Minimum (m)
2	1 DP 0	630	-0.005	1.5871E+07	5.4595E-05	1.7155E-10
3	2	567	-0.005	1.3983E+06	3.537E-06	9.5418E-11
4	3	693	-0.005	1.5871E+07	5.4595E-05	1.7155E-10
5	4	630	-0.0055	1.5871E+07	5.4595E-05	1.7155E-10
6	5	630	-0.0045	1.5871E+07	5.4595E-05	1.7155E-10
7	6	567	-0.0055	1.5425E+06	6.3516E-06	8.3873E-11
8	7	693	-0.0055	1.5871E+07	5.4595E-05	1.7155E-10
9	8	567	-0.0045	1.5871E+07	5.4595E-05	1.7155E-10
10	9	693	-0.0045	1.5871E+07	5.4595E-05	1.7155E-10

Table 1: Table of schematic or Design of Experiment

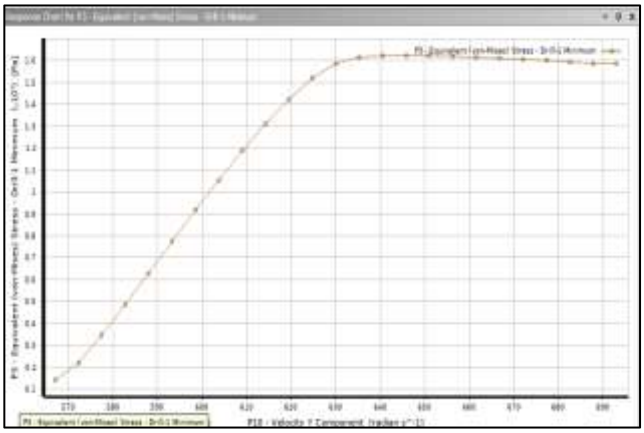
Table of Outline A12: Min-Max Search

	A	B	C	D	E	F
1	Name	P10 - Velocity Y Component (radian s^-1)	P11 - Displacement Z Component (m)	P3 - Equivalent (von-Mises) Stress - Drill-1 Minimum (Pa)	P4 - Equivalent Elastic Strain - Drill-1 Minimum (m m^-1)	P9 - Total Deformation - Drill-1 Minimum (m)
2	Output Parameter Minimums					
3	P3 - Equivalent (von-Mises) Stress - Drill-1 Minimum	567	-0.0051146	8.318+05	2.2725E-06	6.4513E-11
4	P4 - Equivalent Elastic Strain - Drill-1 Minimum	567	-0.0050041	[illegible]	2.1428E-06	6.0575E-11
5	P5 - Total Deformation - Drill-1 Minimum	576.15	-0.005124	1.5515E+06	[illegible]	7.9689E-11
6	Output Parameter Maximums					
7	P3 - Equivalent (von-Mises) Stress - Drill-1 Minimum	635.44	-0.0053098	1.6298E+07	[illegible]	1.7763E-10
8	P4 - Equivalent Elastic Strain - Drill-1 Minimum	646.48	-0.0050588	[illegible]	5.6079E-05	[illegible]
9	P6 - Total Deformation - Drill-1 Minimum	658.79	-0.0052371	[illegible]	[illegible]	1.8338E-10

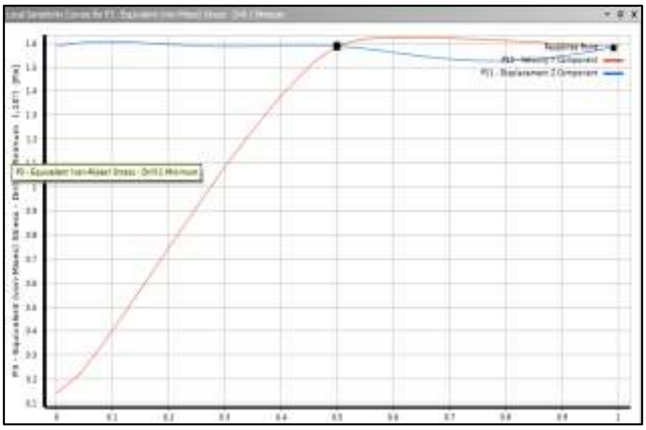
Table 2: Table of Minimum-Maximum Search for Equivalent Stress, Equivalent Elastic Strain and Total Deformation



Graph 1: Goodness of Fit for Equivalent Stress, Equivalent Elastic Strain and Total Deformation

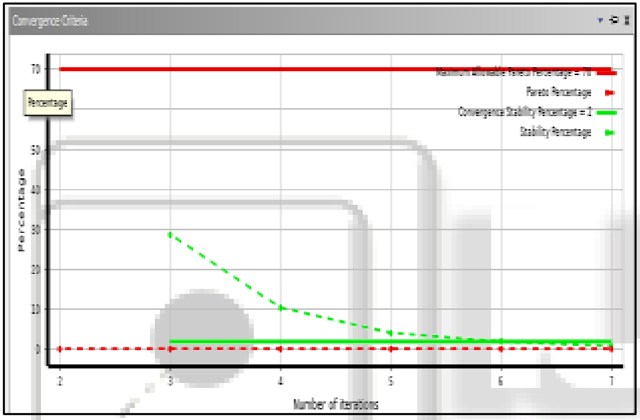


Graph 2: Response chart for Equivalent Stress Vs Cutting velocity

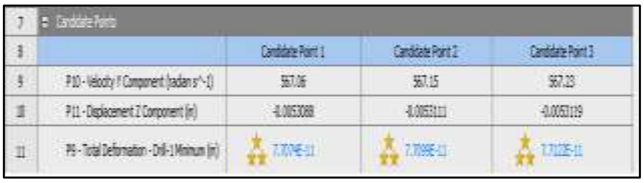


Graph 3: Local Sensitivity curve response point with respect to Equivalent Stress for Cutting Velocity Vs Feed

Graph 1, 2 & 3 provide the curves of the Response chart, Local Sensitivity chart and Local Sensitivity curve with whole parameters considering Equivalent Stress, Equivalent Elastic Strain and Total Deformation with respect to Velocity & Displacement.



Graph 4: Convergence Criteria for Minimum Total Deformation with respect to Optimum Cutting Velocity & Feed

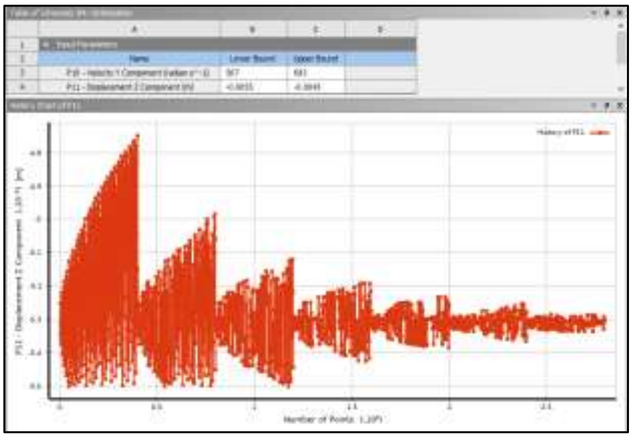


7	⊟ Candidate Points			
8		Candidate Point 1	Candidate Point 2	Candidate Point 3
9	P10 - Velocity Y Component (radian s^-1)	567.06	567.15	567.23
10	P11 - Displacement Z Component (m)	-0.0053088	-0.0053111	-0.0053119
11	P9 - Total Deformation - Drill-1 Minimum (m)	★★★ 7.7074E-11	★★★ 7.7098E-11	★★★ 7.7112E-11

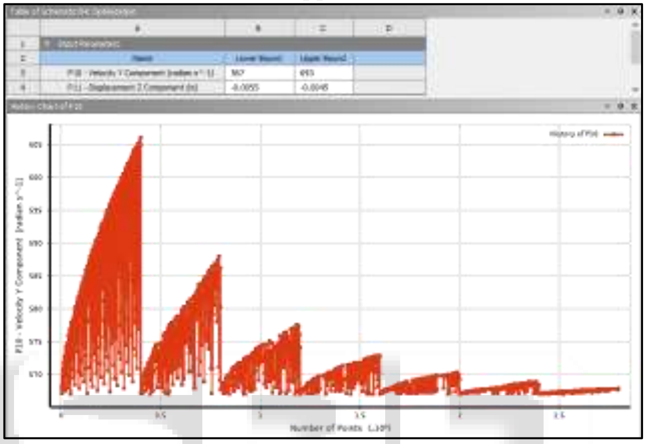
Table 3: Optimum values of Cutting Velocity & Feed for respective minimum Total Deformation

The Optimization model fitted for Minimum Total Deformation was obtained using Ansys software and is represented by the Table 3. The Explicit Dynamic Total Deformation is taken as an Input value of the programme, whereas the Cutting Velocity & Feed were taken as target values of the programme.

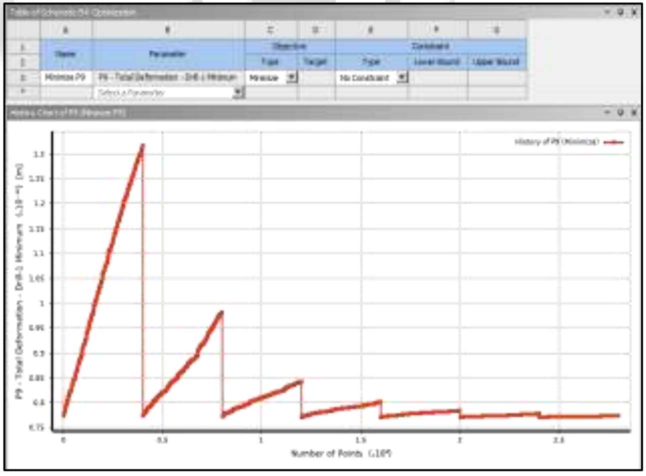
The Surface Optimization analysis is done in ANSYS 18.1 software.



Graph 5: Optimization chart for Displacement within Lower Bound and Upper Bound limit



Graph 6: Optimization chart for Velocity within Lower Bound and Upper Bound limit



Graph 7: Optimization chart for Minimum Total Deformation with respect to Optimum Velocity & Displacement

The Predicted Total Deformation is taken as an Input value of the programme, whereas the Velocity & Displacement within limits of bounds were taken as target values of the programme. And according to Response Surface Optimization analysis value of Cutting Velocity of drilling cutter is 567.06 rad/s and Feed of work piece is 5.3088 x 10^{-3} m for minimum Total Deformation 7.7074 x 10^{-11} m.

VI. CONCLUSION

In this study, Drilling Cutter process, which is mainly used for producing different holes in drilling process, has been analyzed by Finite Element Method. A simplified and idealized finite element model by using symmetry assumption and a non-simplified finite element model of process have been used in the analyses.

- Rectangular section of the Non-linear AL 1100 work piece has been examined.
- The Total Deformation, Equivalent Stress and Equivalent Elastic Strain exerted by the Drilling tool on the work piece during a machining have been identified in order to control the tool deflection.
- The aim of study is to predict the effects of cutting parameters on the Drilling Cutter during Drilling operation on AL 1100.
- Response Surface Optimization is done for achieving the optimum Cutting Velocity of Drilling Cutter & Feed of work piece for minimum Total Deformation of the Tool.

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