PREDICTION THE EFFECT OF MILLING PARAMETERS UPON THE RESIDUAL STRESSES THROUGH USING TAGHUCHI METHOD

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ABSTRACT :-

The important role in the performance of machined parts and structures is residual stresses, namely, in the following aspects corrosion resistance, fatigue life and part distortion. The aim of this research was to predict the residual stresses in aluminum alloy Al-6061 workpiece after machining; this prediction of residual stresses was applied with different value of cutting speed, feed rate and depth of cut using Taguchi method.

The model is verified with experimental measurements of residual stresses. With the analytical model presented in this work, Feed rate is the most important variable that affect on maximum residual stress after that cutting depth and rotational speed substantial reduction in computational time is achieved in the predictions of residual stresses. The result of this research is the contribution of depth of cut, rotational speed and feed with respect to residual stress is (67.07, 24.8 and8.13) % respectively.

KEYWORDS : Taguchi method, CNC milling machine, machining parameters, residual stress, ANOVA.

تخمين تاثير متغيرات عملية التفريز على الاجهادات المتبقية من خلال استخدام طريقة تاكوشي

عقيل صبري بدن

الخلاصة :-

تلعب الاجهادات المتبقية دورا هاما في أداء الاجزاء المشغلة والهياكل ، في ما يتعلق بعمر المنتج، ومقاومة التآكل وتشويه الجزء. الهدف من هذا البحث لتخمين الاجهادات المتبقية في سبائك الألومنيوم Al6061 بعد عملية التشغيل. تم تطبيق هذا التنبوء للاجهادات المتبقية مع قيم مختلفة من سرعة القطع، معدل التغذية وعمق القطع باستخدام طريقة تاكوشى . تم التحقق من النموذج التحليلي المقترح في هذا البحث بالمقارنة مع الفحوصات العملية للاجهادات المتبقية ،حيث وجد ان اعلى اجهاد متبقي بالمعدن يتاثر بمعدل التغذية يتبعه عمق القطع وبعدها سرعة القطع وبتحقيق تخفيض كبير في وقت الحساب لتوقعات الاجهادات المتبقية بالمعدن. تم الاستنتاج من هذا العمل بان تاثير السرعة، معدل التغذية وعمق القطع على قيم الاجهادات المتبقية هو (24.8و8.13 و67.7) بالتتابع اي ان عمق القطع له تاثير عالي على قيم الاجهادات المتبقية يتبعه سرعة القطع وبعدها معدل التغذية .

كلمات دالة : طريقة تاكوشي ، مكائن القطع ذات التحكم الرقمي ، عوامل عملية القطع ، الاجهادات المتبقية ، طريقة انوفا .

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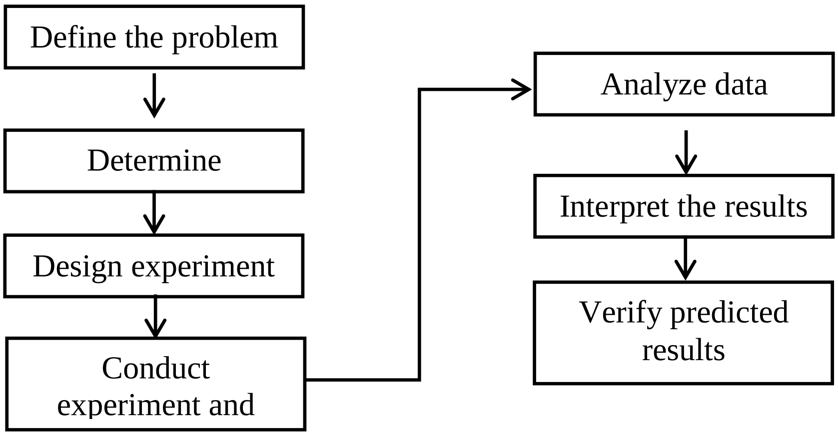
INTRODUCTION :

Machining process is the complex operations that need more investigation and research. The output of the process is complex with respect to the input parameters, a large change in the output parameters happen when small change in one of the input parameters. Residual stress is the important factor that influences corrosion resistance, dimensional accuracy, and fatigue life of machined parts and is a major component of surface finish [O. Belgasim and et al -2010]

The sources of residual stress are including plastic deformation of a material and widely varied or volume changes of a material due to thermal gradients. The residual stresses are typically a result of thermal gradients due to change in volume of the material. During the contact between the machined parts, the tool and chip formation caused the plastic deformation. In other wise, the effect of temperature and stress on the material behavior may influence residual stresses during loading. As a result, on a machined surface modeling the residual stress formation is a challenging task. Residual stress prediction is as important as ever. There are still opportunities for advancing predictive residual stress methods[Jiann-Cherng Su-2006]. The objectives of the current research are as follows: (1) validate the methodology with experimental data (2) the machining process based on an analytical description and develop a method of predicting residual stress . **A series** of experiment have been carried out in design of experiments to investigate the effect of cutting variables like rotational speed, cutting depth and feed rate on residual stress in vertical milling operation. The rest of literature review has been presented in **Table (1)**.

EXPERIMENTAL WORK

Plan of Experiments



An important stage in response surface model generation by ANOVA is the planning of experiments. The factors which has a significant influence on residual stress was identified they are rotational speed, feed rate and depth of cut of milling process.

Methodology of the experimental data

ANOVA methodology is a collection of mathematical and statistical techniques for empirical model building. By careful design of experiments the objective is predict a response which is influenced by several independent variables. An experiment is a series of tests, called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response .

Material and process:

The experimental work was conducted in dry cutting conditions on a C-tek three-axis (KM-80D), with a maximum rotational speed of 6000 (r.p.m) feed rate of 10 m/min. the tool paths and CNC part programs were created using MATLAPR2014-package. The material of workpiece was used Aluminum (Al 6061) in cylinder form (Ø40x30)mm. The experimental work of the workpiece is machined the square pocket (20x20x15)mm using the end mill tool that illustrated in **Figure (1)**. The chemical test has been carried out (State Company for Inspection and Engineering Rehabilitation activities (S.I.E.R)), and the information of mechanical properties and chemical composition of Aluminum (Al 6061) alloy is illustrated in **Table (2)**. The cutting tool used for performing flat milling operation is (3-flutes, 6mm diameter) uncoated tungsten carbide for better surface quality and material remove rate.

The machined surface was measured at four different angles using a ORIONRKS 6000 test measuring instrument (the X-ray diffraction technology was used to detect the residual stress) with the angles (0^o, 15^o, 30^o and 45^o) and the average residual stress value is recorded in (MPa) that illustrated in **Figure (2)**, the residual stress in original blanks is (-1.419 MPa).

This specialized stress analysis system is using the side-inclination method was included stress analysis software. The stress analysis sample stand and X-ray tube. X-ray stress analysis is widely used to measure the level of stress in substances. In the X-ray diffractometry of stress extremely small changes in the lattice space were measured from the X-ray diffraction pattern profile. The precise measurement of the residual stress allows the use of the special stress analysis stand associated with the side-inclination method. Free of absorption error is used in this technique. The software includes following functions, as measurement, peak position calculation, width at half height and stress calculation. Depending on the type of reflective plane and sample, either the Co tube or Cr X-ray tube is necessary.

The acting single stress measure in some direction in the surface σϕ. Shows an isotropic solid that the strain along an inclined line according to elasticity theory (m3 in **Figure 2**) is[M.E. Fitzpatrick, et al-2005].:

$$\varepsilon_{\emptyset\psi} = \frac{1+\upsilon}{E}(\sigma_1 cos^2\phi + \sigma_2 sin^2\phi)sin^2\psi - \frac{\upsilon}{E}(\sigma_1 + \sigma_2) \qquad (1)$$

To evaluate the stresses when consider the strains in terms of inter-planar spacing and then it can be shown that

$$\sigma_\phi = \frac{E}{(1+\nu)\sin^2\psi}\left(\frac{d_\psi - d_n}{d_n}\right) \qquad (2)$$

$\epsilon_{\phi\psi}$	Strain measured in the $\phi\psi$ direction	-
v	Poisson's ratio	-
E	Elastic modulus	GPa
σ_1 , σ_2	Principal stresses acting in the principal directions	MPa
ϕ	Angle among the projection of the diffracting plane and a fixed direction in the plane of the sample	deg.
ψ	Angle among the normal of the diffracting plane and the normal of the sample (diffracted beams and bisecting the incident)	deg.
d_ψ	spacing Inter-planar in ψ direction	Å
d_n	Inter-planar spacing of planes normal to the surface	Å

This equation allows to determine from two measurements made in the direction of the stress to be test and a plane normal to the surface. The best method to finding residual stress is the (sin2ψ) method [M.E. Fitzpatrick, et al-2005]. At different psi tilts, a number of XRD measurements are made. The 2-theta peak position or inter-planar spacing is tested and plotted that illustrated in **Figure (2)**.

Design of experiments

Taguchi algorithm became a good tool to improve productivity through research and development in recent years. Thus at low cost that can be produced high-quality products rapidly. With a small number of experiments Taguchi method uses a special design of orthogonal arrays to study the entire parameter space. At three levels the methodology of Taguchi was used for three factors that implementation of the plan of testing. To define the nine trial conditions, used the six degrees of freedom at this study and Taguchi's (L9) orthogonal array. The levels and process parameters are illustrated in **Table (3)**. The average response and Replicated twice values for each of the nine trials or process designs were used for this work. **Table (4)** illustrated the present work and the tests results, and **Figure (3)** presents the relationship between experimental data .

OPTIMIZATION OF MACHINING PARAMETERS :-

To gather experimental data using a Taguchi approach was employed. Then, the best set of cutting parameters has been found according to signal to noise (S/N) ratio. These parameters values were used the residual stress of Al6061 parts maybe predict, optimum cutting parameters are required that found for the efficient via the machine tools. The milling process parameter optimization is time consuming and highly complex. Taguchi parameter optimization methodology is applied in this work to optimize cutting parameters in milling process.

As stated above, to performance characteristics there are three categories, i.e., the higher-is-better, the nominal-is-better and the lower-is-better. For optimal performance machining, they should be taken the lower-is-better performance characteristic for residual stress. And using Eq. (3) can be calculating the corresponding S/N ratio. Since the experimental design is orthogonal, then it is possible to separate out the influence of each cutting parameter at various levels. For each level of the cutting parameters the mean S/N ratio can be computed that called the mean S/N response table for the residual stress and summarized in **Table (5)** In addition, one way-ANOVA was used in this work, the ANOVA results for the nine experiments is also calculated and listed in **Table (6)**.

The use of the best type, the response is given by :

$$\text{S/N ratio} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} Y_i^2\right] \qquad (3)$$

i = number of trial,
Yi = measured value of the quality characteristic for ith trial condition,
n= number of repetitions.

$$\text{DOF within group} = E-1-S \qquad (4)$$

Where E=No. of experimental test.
S=sum of degree of freedom for process parameters.

Where calculated using above equation the signal to noise ratios for each of the nine experimental conditions. In terms of mean response and in terms of S/N ratio can be separated the factors affected out .

RESULTS AND DISCUSSION

Figures (3) show the effect of various variables of machining parameters (rotation speed, feed and cutting depth) on average residual stresses that occurs on the machined parts of Aluminum alloy (Al-6061) that were machined in milling process. The figures were result from the experimental work using ANOVA algorithm. The effects of two input parameters represents in each curve in otherwise the parameter was kept constant.
The effect of rotational speed on the maximum residual stress at the different feed rates and depth of cut were used. while, high compressive residual stress are founded by using maximum rotational speed and depth of cut as shown in **Figure (3)** shows that the decrease in rotation speed caused a decrease in the maximum compressive residual stresses, and vice versa. Therefore lower feed rate are more acceptable on tensile stresses. Since tensile stresses are not acceptable as they can lead to fatigue and cracking. In this work, with respect to the range of cutting parameters used, explain that at the highest values of cutting speed and the highest depth of cut occurs maximum compressive residual stresses, see **Figures (4) and (5)**. While **Figure (6)** presents the variance of residual stress with respect to three process parameters.
The effect of cutting depth on maximum residual stresses is not the same. The maximum compressive residual stress increases considerably with an increase in cutting depth at low feed rates, while the maximum compressive residual stress considerably decreases as the depth of cut is increased at high feed rates. The compressive residual stresses in mechanical parts is often favorable rather than tensile stresses as the compressive stresses present an important role in the function and parts service life .

CONCLUSIONS :

The current research reviewed some important aspects related with residual stresses on machining of materials with special emphasis in Al-alloy. Based on the results of the above research on residual stresses in machining using ANOVA algorithm, the following conclusions can be draw:

1. Compressive residual stresses generally improve component performance and life;
2. In the precision machining of Aluminum Alloy (Al-6061) there is always aims to generation of compressive residual stress.
3. Feed rate is the important variable that affect on maximum residual stress followed by depth of cut, and after that rotational speed.
4. It has been established that Taguchi Algorithm is an effective optimization tool for machining of Al 6061 alloy in milling process.
5. A comparison study is made for tabulated values and experimental values for residual stress by using ANOVA model that result the contribution of depth of cut, rotational speed and feed rate with respect to residual stress is (67.07, 24.8 and 8.13)% respectively.
6. This encourages applying the Taguchi concept for optimizing multiple factors with multi response processing. The analysis of variance illustrate that the cutting depth is definitely the most important variable, followed by the rotational speed and feed rate that influence the multiple performance specifications.

Figure (1) (a) Experimental set up for milling operation (b) nine-actual workpiece

Figure (2) Set up for residual stress measurement and Residual Stress Analysis Result Screen (X-ray software output)

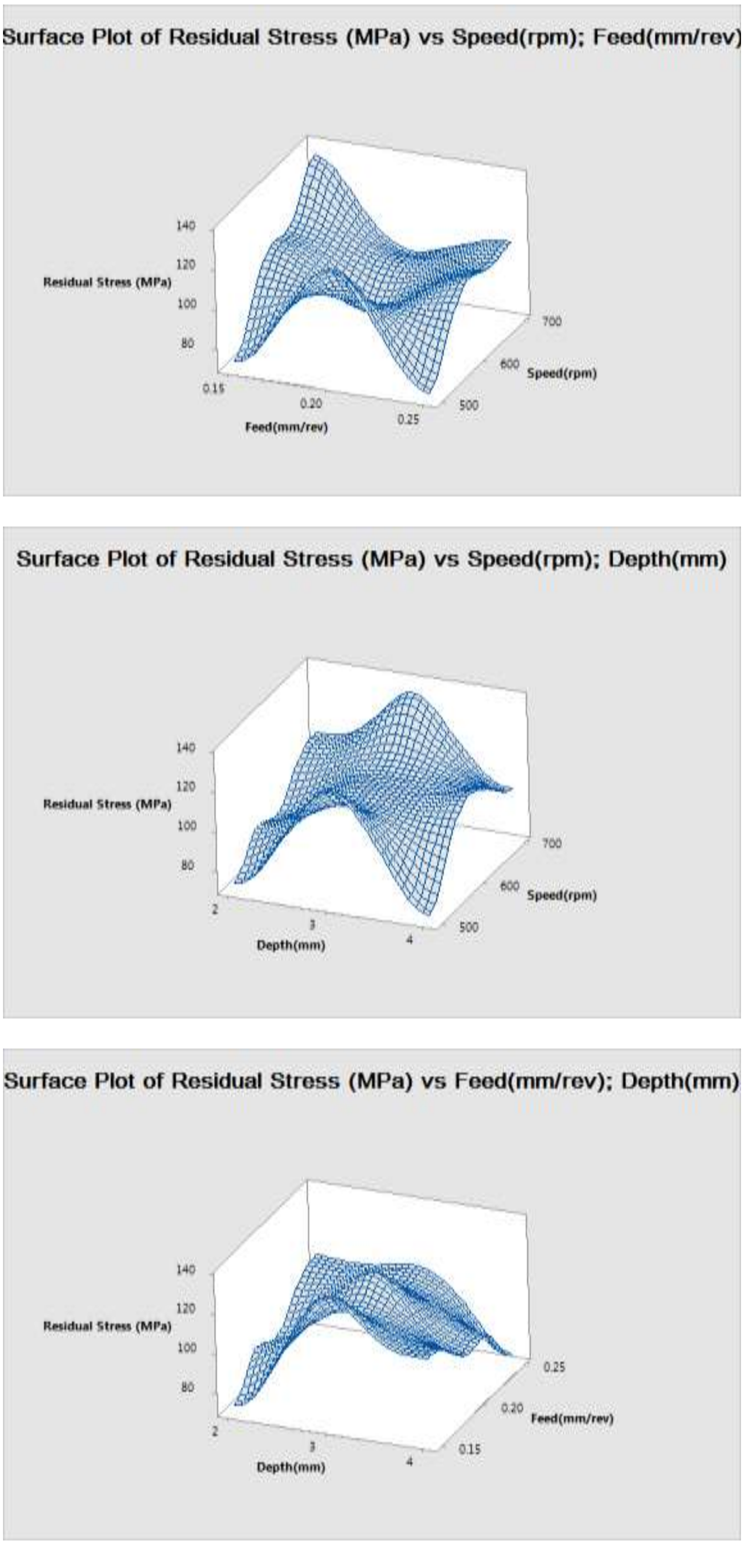


Figure (3) Relationship between residual stress (negative values) and process parameters

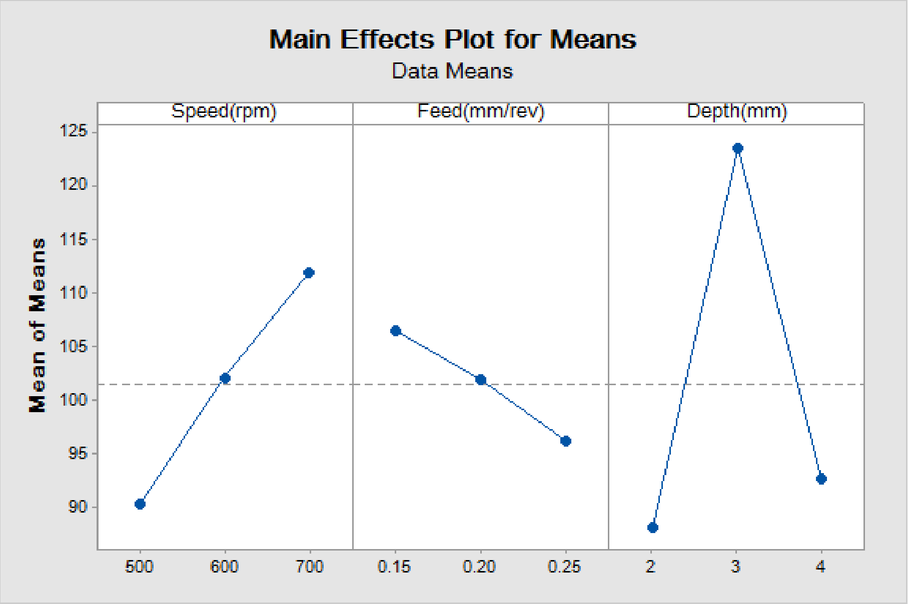


Figure (4) Relationship between mean residual stress (negative values) and process parameters

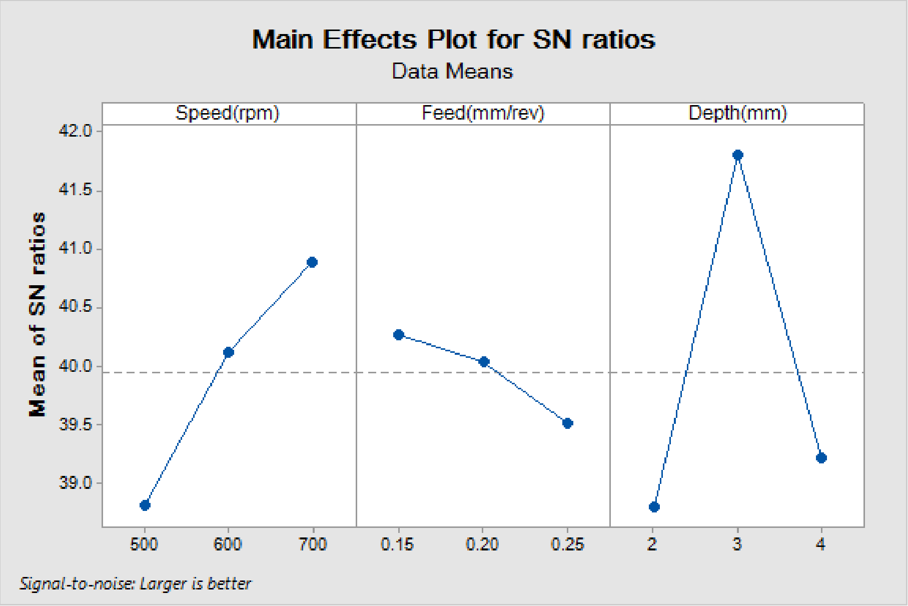


Figure (5) Relationship between S/N ratio and process parameters

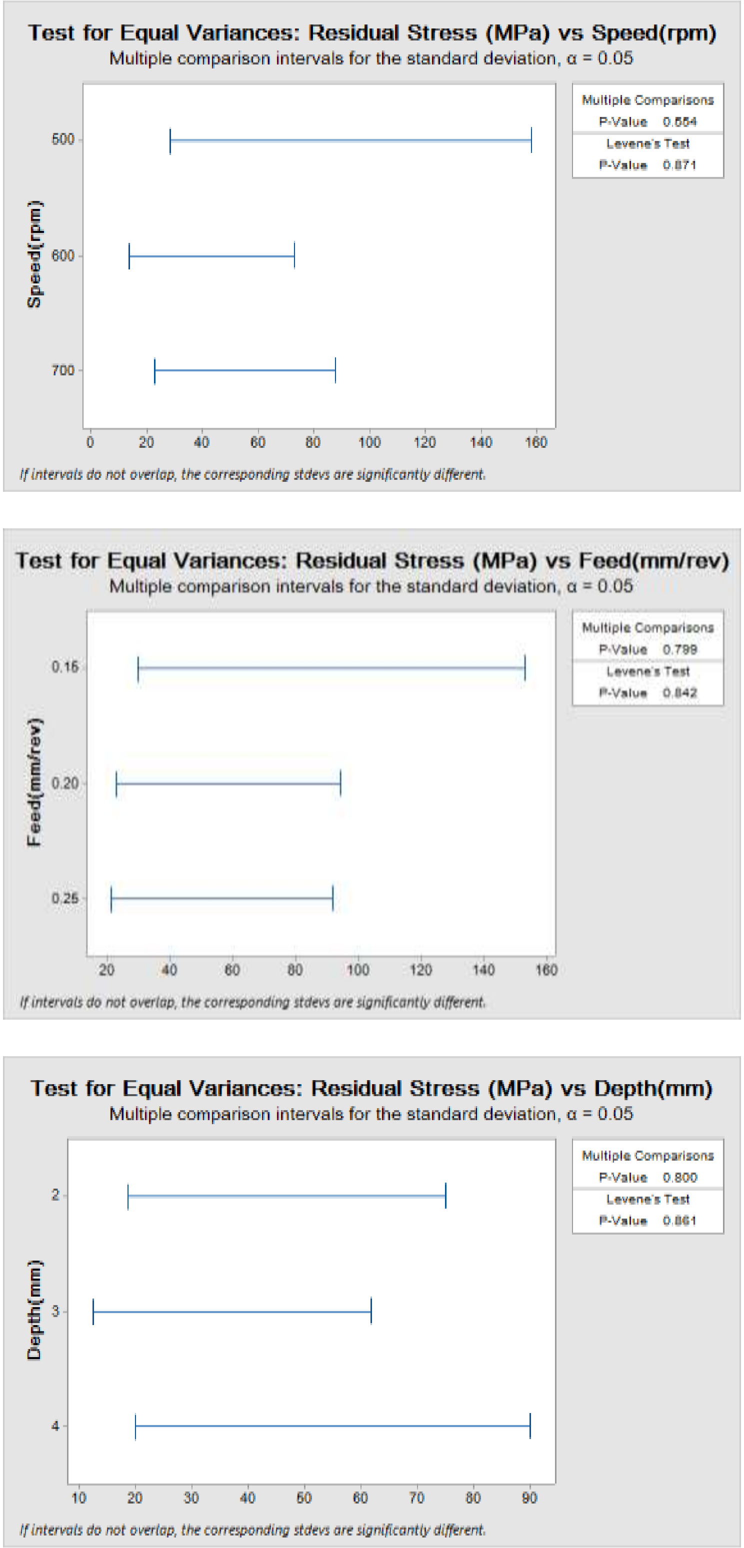


Figure (6) illustrated variance of residual stress (negative values) with respect to process parameters

Table (1) Literature review focusing on optimization approach in milling operation

No.	Authors	Optimization Approach	The aim of work
1	T. O¨ zel and et al (2012)	Finite element method	prediction of residual stresses
2	M. Cebron and et al (2012)	Taguchi method	prediction of residual stresses
3	C. Maranh and et al (2012)	Finite element method	Analysis the residual stresses
4	Z. T. Tang and et al (2012)	Finite element method	Analysis the residual stresses
5	Vikas B. Magdum and et al (2013)	Taguchi method	optimization of residual stresses
7	Walid Jomaa and et al (2014)	Taguchi method	optimization of residual stresses
8	Chaofeng Liu and et al (2015)	Finite element method	Analysis the residual stresses
9	Sohail Akram and et al (2015)	Finite element method	identify the sensitivity of the residual pressure to process parameters

Table (2) Mechanical properties of Al 6061 alloy and chemical composition of Al 6061 alloy (wt %)

Ultimate Strength (MPa)	Yield Point (MPa)	Elongation (%)	Hardness (HBR)
110-152	65-110	14-16	30-33

Elements	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
Percentage %	95.8-98.6	0.04-0.35	0.15-0.4	Max 0.7	0.8-1.2	Max 0.15	0.-0.8	Max 0.15	Max 0.25

Table (3) process parameters and their levels

Parameters	Unit	Level 1	Level 2	Level 3
Rotational Speed (S)	Rev/min	500	600	700
Feed Rate (F)	mm/rev	0.15	0.2	0.25
Depth Size (D)	mm	2	3	4

Table (4) Experimental layout using an L9 orthogonal array and corresponding results

Expe. No.	Process Parameters			Average Response Values
	Spindle speed rev/min	Feed rate mm/rev	Depth of cut mm	Residual Stresses MPa
1	1	1	1	-72.496
2	1	2	2	-126.484
3	1	3	3	-72.310
4	2	1	3	-111.948
5	2	2	1	-85.232
6	2	3	2	-109.331
7	3	1	2	-134.945
8	3	2	3	-94.084
9	3	3	1	-106.974

Table (5) Result for individual characteristic of mean response and S/N ratio.

	Mean response			S/N ratio		
	Speed	Feed	Depth	Speed	Feed	Depth
Level 1	-90.43	-106.46	-91.97	-38.81	-40.26	-39.15
Level 2	-102.17	-101.93	-115.14	-40.12	-40.04	-41.20
Level 3	-112.00	-96.20	-97.50	-40.89	-39.51	-39.47
Delta	21.57	10.26	23.17	2.08	0.75	2.05
Rank	2	3	1	1	3	2

Table (6) One-Way ANOVA results of residual stress.

Source of variance	Degree of freedom	Sum of squares, ss	Variance, V	Contribution on (P), %
Rotational Speed (S)	2	1699.321	849.6605	24.8
Feed Rate (F)	2	557.201	278.6005	8.13
Depth Size (D)	2	4533.758	2266.879	67.07
Within group	2	63.024	30.514	0.919
Total	8	6853.304		100

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