Optimization of Process Parameters to Maximize Formability for Better productivity by Using Taguchi Method

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Abstract: The titanium alloys are extensively used in aerospace, automotive field, refineries and in biomedical implant due to its high specific strength, corrosion resistant and biocompatibility. These alloys are to be sophiscately processed, and processing is to be analyzed and optimized for better strength and formability. In the present work standard anisotropy tests have been carried out at high temperature as per Taguchi design of experiment with L-9 array. ANOVA analysis has been carried out to determine the parameter that influences the process & their significant effect on the optimum design. The optimized process parameters from ANOVA analysis are temperature 675°C, cross head speed 7.5 mm/min, angle of sample tested to rolling direction is 45degree & pack rolling direction is same to first rolling direction, within the parameters selected in the study, for maximizing anisotropy value which is the measure of drawability.

Keywords*:* Formability, Taguchi, ANOVA, anisotropy,

1. INTRODUCTION

The titanium alloys are backbone of aerospace industry. These new structural materials are with lightweight potential associating high strength to a reduced weight of the parts. But their use is still limited by high cost, unsuitable with conventional manufacturing technologies & formability issues. Contributions are expected on the development, the impact of constitutive models specific to these materials such as anisotropy, onset of necking and strain localization, as well as other phenomena that limit the formability. Moreover, the effect of experimental scatter has become a serious issue for the robust application of formability predictions in an industrial context. To develop the technology for improving the aerospace material's intensive & extensive properties for better formability & crash worthiness is need of the day. Research on its formability aspects is required to develop useful components of complex shapes out of this material. One of the ways to measure the formability is its deep drawability characteristics. Formability of sheet metal is the ability of the material to be formed into a specific shape without fracture. In sheet metal forming, in a majority of cases uni-axial or biaxial or uni-axial and biaxial stretching takes place.

On the material side the properties that govern the formability are - Strain hardening exponent 'n'. Another important factor influencing sheet-metal forming is anisotropy, or directionality of Sheet metal. There are two types of anisotropy-crystallographic anisotropy (Due to preferred Orientation of the grains) and mechanical fibering (due to the alignment of impurities, inclusion, voids etc. throughout the thickness of the sheet during processing). Anisotropy may be present not only in the plane of the sheet, but also in its thickness direction. The former is called planar anisotropy and the latter normal or plastic anisotropy. In sheet metal that has been strained by uniaxial tension sufficiently to induce plastic flow is the ratio of the true strain that has occurred in a width direction ε_w perpendicular to the direction of applied stress and in the plane of the sheet, to the thickness direction ε_t. The plastic strain ratio r is a parameter that indicates the ability of a sheet metal to resist thinning or thickening when subjected to either tensile or compressive forces in the plane of the sheet. This resistance to thinning or thickening contributes to the forming shapes, such as cylindrical flat bottom cups, by the deep-drawing process. The '*r*' value, therefore, is considered to measure of sheet metal drawability [1]. It is generally recognized that the high *r* value is useful for improved drawability [2]. The process related variables that dictate formability are Design variables consisting of shape and curvature of the component ,Die attachment hold down pressure. It may be noted that uniform strain distribution results in better formability.

In this study, the significance of three important process parameters of formability has been determined. Taguchi analysis has been used to determine the influence of process parameters on the formability. It is essential to determine the degree of influence of process parameters on the formability in order to optimize appropriate conditions to maximize the formability. The process parameter of blank temperature opens up the possibility of significantly improving the ductility of the material and the associated forming capacity. On the other hand, it also offers the possibility of significantly reducing the yield point that helps in reduction of the forming forces and pressures. The formability can be improved by using differential temperature rather than a uniform temperature rise [3-4]. The effect of warm forming on drawability of both rectangular and circular cups has shown positive results [5] and at elevated temperature better results [6]. So it is essential to determine the degree of influence of process parameters on the formability in order to optimize appropriate conditions to maximize the formability at high temperature.

These high strength alloys are desirable to reduce the weight and cost but lacks in formability. However, the enhancement of the formability of this material is a big challenge. There has been little research on the influence of process parameters on formability .Taguchi method has been applied by several researchers in forming studies to design the experiments and to determine the influence of process parameters on the formed cups. Taguchi method has been used to optimize flow-forming process for maximum deformation of the formed tube [7-8-9]. It is evident that the optimal curvature varies with the interfacial friction (mf), with the material strain hardening with the drawing ratio but not with the blank thickness [10].

Taguchi Techniques and Analysis of Variance

Taguchi method is a strong technique for the design of high quality systems [11-12-13] and has been used in engineering design [14-15]. It can be used by users with limited knowledge of statistics & has wide popularity in the engineering and scientific community [16]. The Taguchi method has been used in many scientific fields such as optimizing CNC end milling process parameters to provide good surface finish as well as high material removal rate [17-18]. A simple and efficient way to study the influence of injection molding variables on sink marks by using Taguchi approach [19]. The experimental investigation and statistical analysis on formability of titanium alloy on the basis of anisotropy has not been studied by the researchers. Hence, the main objective of this research work is to investigate the process parameters which will give optimized value of anisotropy which is a measure of drawability [1] to maximize formability and productivity in aero space industry.

2. PRESENT WORK

The material selected in the present work is titanium alloy Titan 31. The material was received as rolled & annealed condition of 8mm thickness sheet metal. The chemical composition of the material is as shown in the table 1. The tensile test was carried out at room temperature & ultimate tensile strength, 0.2% ps,& percentage elongation has been evaluated and shown in table 2.

Table 1
Chemical Composition of Material by Weight

C	*O*	*N*	*H*	*AL*	*V*	*Fe*	*Ti*
0.018	0.1755	0.003	0.0035	6.36	4.19	0.04	balance

Table 2
Tensile Properties at Room Temperature

0.2% PS	*UTS*	*% Elongation*
930MPa	1022Mpa	16%

The material has been processed under alpha-beta rolling process ie rolling material at 900 °c and at 850 ° in a direction then pack rolled in 90°, 45°& in same direction to first rolling direction at 800°c .The pack rolled materials are annealed at 800°c with soaking period of one hour. The specimens have been extracted from alpha-beta processed & annealed sheet in the direction of final rolling, 90 degree to final rolling & in 45 degree to final rolling directions by using EDM wire cut machine Sprintcut as shown in fig. 1.

Figure 1: EDM Wire Cut Machine

As the room temperature formability of titanium alloy Ti6Al 4V is very less & not suitable for productivity in aero space division, the high temperature has been selected for the better formability & productivity. High temperature tensile test has been carried out by using Tensile testing machine-INSTRON 5500R. Taguchi's design of experiment (DOE) has been selected with four factors ,each of three levels, as shown in Table 3. The fractional factorial design used is a standard L27 (3orthogonal array) [20]. However, according to Taguchi's DOE, L9 orthogonal array for three factors has been used in the present investigation for achieving economy for high temperature work and due to its capability to check the interactions among f actors. The L-9 orthogonal array is given in table 4.

The specimen are drawn in standard tensile test and interrupted at an instant to measure width of specimen at different positions within gauge length to calculate mean value. The ε_w has been calculated from the obtained lateral contraction. As *r* is numerically equal to $r = \varepsilon_w / \varepsilon_t$ [1]

Table 3
Details of Process Parameter and their Level

Factors	*Levels and range*		
	Level 1	*Level 2*	*Level 3*
Temperature in °c	675	725	775
Cross head speedMm/min	0.75	7.5	75
Specimen extracted in angle to rolling direction in degree	0	45	90
Pack rolling direction in degree to first rolling	90	45	0

Table 4
L-9 Orthogonal Array of Taguchi Method

Parameter combination	*Tempera-ture In °c*	*Strain Rate s^{-1}*	*Specimen extracted in angle to rolling direction in degree*	*Pack rolling direction in degree to first rolling*
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1
total	18	18	18	18

3. RESULT & DISCUSSION

The high temperature tensile tests have been carried out at random order to avoid random errors as per Taguchi L-9 array .The anisotropy of the material has been calculated according to ASTM E517 by Assuming the volume remains constant. The r has been calculated as $r = \ln(w_o/w_f) / \ln(l_f w_f)/(l_o w_o)$. Where w_o is the initial width of gauge of specimen, l_o is the initial gauge length. And l_f & w_f are the final gauge length and final width of gauge of specimen. The obtained value of anisotropy in each trial of L9 array has been used in the software QUALITEK-4 in the result column of Taguchi experiment configuration. The quality characteristic -bigger is better has been used for standard analysis.

Average effect of factors and Interactions: The average effect of parameters temperatures, cross head speed &angle of sample tested to rolling direction &pack rolling direction to first rolling has been shown in fig 2 and their magnitude in table 5.

It is evident from table 5& fig 2 that temperature has maximum value of level- 1 for anisotropy , cross head speed has maximum value of level-2 and specimen extracted angle to rolling direction has maximum value of level-2 and pack rolling direction of level 3,for maximum anisotropy. Percent contribution of pack rolling direction to first rolling is more than other factors selected in the study as given in fig. 3.

Table 5
Influence of the Parameters

parameters	*tempera-ture*	*Cross head speed*	*Angle to rolling specimen tested*	*Pack rolling direction to first rolling*
Level 1	3.999	3.547	3.545	3.883
Level 2	3.594	3.569	4.101	2.367
Level 3	2.881	3.279	2.749	4.145

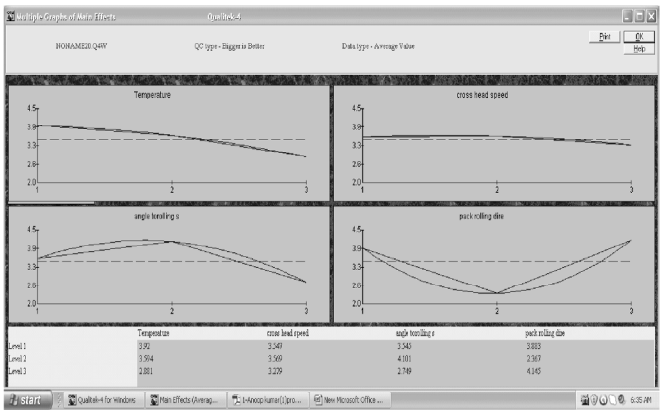

Figure 2: Main Effect of Levels of Parameter -temperature, Cross Head Speed, Angle to Rolling Direction & Pack Rolling Direction to First Rolling

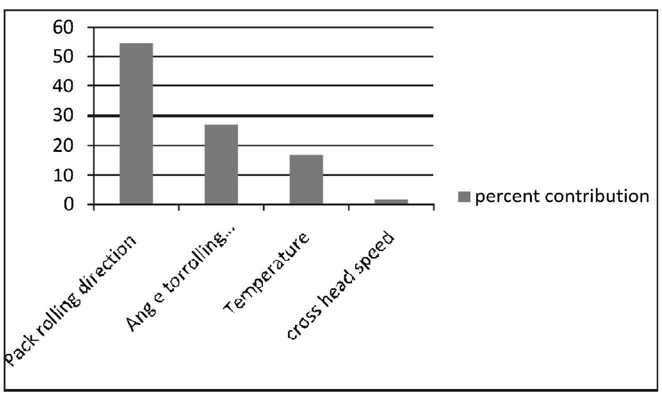

Figure 3: Per cent Contribution of Factors

ANOVA Analysis

The degree of difference or similarity between two or more groups of data can be determined by ANOVA analysis. It is based on the comparison of the average value of a common component and identifies the important parameters. The percentage influence of each parameter on different quality characteristics can be calculated. Confidence interval is the variation of the mean performance at the optimum condition. Variation reduction results have been analyzed by using standard analysis. ANOVA analysis has been carried out to optimize the parameter that influences the anisotropy which is the measure of formability. The optimized parameters are temperature of level -1; crosshead speed, specimen tested in angle to rolling direction are of level-2 and pack rolling direction to first rolling of level 3,as given in table 6.

Table 6
Optimal Conditions & Performance

Factor	*Level description*	*level*
Temperature	675°c	1
Cross head speed	7.5 mm/min	2
Angle to rolling specimen tested	45 degree	2
Pack rolling direction to first rolling	O degree	3

5. CONCLUSION

Anisotropy value has been determined at different temperatures as per Taguchi Design of experiment considered in the study.

It has been found that the angle of pack rolling to first rolling direction has maximum significant influence on the anisotropy within the parameters selected in the study.

ANOVA analysis has been carried out to optimize the parameter that influences the anisotropy which is the measure of formability. The optimized parameters are temperature of level -1, crosshead speed , angle of specimen tested to rolling direction is of level -2and pack rolling direction to first rolling direction of level- 3.

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