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Taguchi statistical analysis of experiments on the effect of cutout on crack growth and fatigue life of ck45 steel

Amin Saber
Department of Mechanical Engineering
Ferdowsi University
Mashhad, Iran
Saber.sut89@yahoo.com

Mahmoud Shariati
Department of Mechanical Engineering
Ferdowsi University
Mashhad, Iran
Mshariati44@um.ac.ir

***Abstract* — in this study the effect of cutout with different geometries on the fatigue crack growth path and fatigue life of CK45 steel under pure mode-I loading is investigated by taguchi statistical analysis. The effect of four parameters: initial crack angel, cut out geometry, size of cutout and vertical distance of cutout from edge crack are investigated using taguchi analysis. Due to number of parameters and values of each parameter L-9 array is chosen. The aim of this study is increasing fatigue life of steel plate and determining of contribution of each parameter in the fatigue life. The results show that the size of cutout and vertical distance of cutout from edge crack are the most effective parameters in the crack path and fatigue life so the importance of these parameters causes increasing fatigue life of steel plate.**

Keywords-component; formatting; style; styling; insert (key words)

I. INTRODUCTION

Plates and shells have many applications in the mechanical structures, aviation, marine, and automobile industries. Circular cutouts because of the geometry and the many applications, have been considered by many researchers [1-3]. Ulza and Semercigilb [4] used standard finite element method to present numerical modelling of dynamic behaviour of perforated plates. Savin and Guz [5] presented the perturbation solutions for stresses around elliptical holes in cylindrical and spherical shells. In discussing of analysis of durability of the structures, prediction of crack growth path is as important as prediction of fatigue life of components in order to safety of them. Many factors affect fatigue crack growth path, such as: type of material (micro structure), geometry and loading condition. Holes act as stress concentrators and make a stress field near it. This stress field can affects in the stress intensity factor of crack tip and causes deviation of propagation path of crack. Riveting holes in the aircraft, ships and components, which are loaded with variable amplitude are good examples to illustrate the importance of considering and examine the growth of fatigue cracks around the holes. Growth of fatigue cracks around the hole under constant amplitude loading has been studied [6-9]. The study of small fatigue crack behaviour has been focused on constant amplitude mode I loading in prior studies. However possible non-planar crack growth and complex external loading will obtain in mixed-mode fatigue crack growth of small cracks. Prior study shows that prior loading history involving random loading or multiple overloads can influence fatigue crack growth thresholds [10-13]. In this study, the fatigue crack growth path and affective factors on changing fatigue crack growth path will present. The effect of various parameters such as cutout geometry, cutout size, position of cutout and initial edge crack on the fatigue crack pass is investigated. The experiment setup designed using taguchi analysis in order to determine contribution of each parameter on crack growth path.

Basically, the Taguchi method is a powerful tool for the design of high quality systems. It provides a simple efficient and systematic approach to optimize designs for performance, quality, and cost. The methodology is valuable when the design parameters are qualitative and discrete. Taguchi parameter design can optimize the performance characteristics through the settings of design parameters and reduce the sensitivity of the system performance to sources of variation. In recent years, the rapid growth of interest in the Taguchi method has led to numerous applications of the method in a world-wide range of industries and nations [14].

Studies have ever been conducted in this area were to check out some of the design parameters alone or a

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number of them together. But using the Taguchi method can be a combination of these parameters simultaneously and achieve the optimal condition for each parameter. The aim of this study is using the Taguchi method and prioritizing the influence of design parameters on the fatigue life of steel.

II. MATERIALS AND PRECEDURE

A. *Design of experiment*

In this study effect of four parameters on the crack growth path are investigated. Each parameter presented in 3-levels as shown in table 1. According to table 1 in order to number of parameters and level, taguchi *L-9* array is used for the design and analysis of experiments. The number of experiments can be designed in this way is 9 that compared with the general conditions may be saving time and money. Design of experiment by the taguchi method is shown in table 2.

Table1. Parameters and levels required for taguchi method.

Design Parameter	Level 1	Level 2	Level 3
Initial crack angle (θ)	0 deg	15 deg	30 deg
Geometry of cutout	circle	triangle	square
Size of cutout (d)	15mm	20mm	25mm
Position of crack(h)	15mm	20mm	25mm

Note that in Table 1. the position parameter is the vertical distance of the center of cutout to the edge crack. The following figure shows the geometry of specimen.

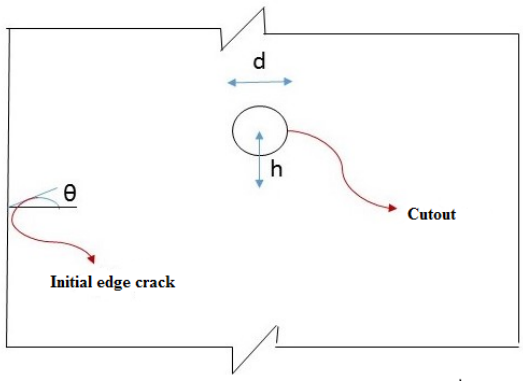

Figure1. Geometry of specimen with circular cutout

In figure 1, θ, d, h are initial crack angle, height of cutout and vertical distance from center of cutout to edge crack respectively.

B. *Experimental tests*

In order to determine the properties of the material, tensile test according was conducted according to ASTM-E8 standard by servo hydraulic *Zwich/Roell* machine with capacity of 100kN. Tensile test result is shown in figure 2. According to figure 2, yield stress can is about 313Mpa. Due to importance of grain orientation in the fatigue crack growth of steels, the steel was tested in the metallographic laboratory. Grain orientation is show in figure 3 that according to this, it can be concluded that the material properties in the rolling direction and the direction perpendicular to the rolling is not much difference.

Table2. Design of experiment by using taguchi method

	Angle (degree)	Geometry of cutout (mm)	Size of cutout (mm)	Position (mm)
Specimen 1	0	Circle	15	15
Specimen 2	0	Triangle	20	20
Specimen 3	0	Square	25	25
Specimen 4	15	Circle	20	25
Specimen 5	15	Triangle	25	15
Specimen 6	15	Square	15	20
Specimen 7	30	Circle	25	20
Specimen 8	30	Triangle	15	25
Specimen 9	30	Square	20	15

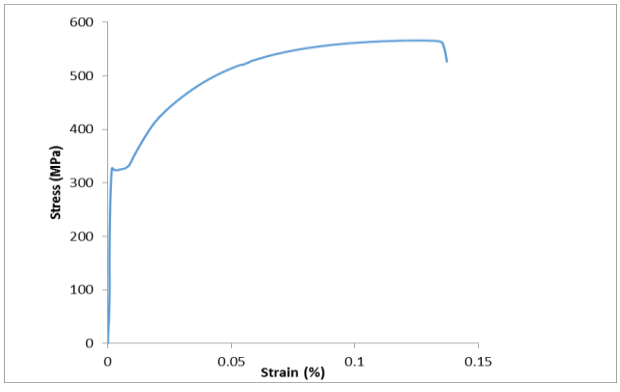

Figure 2. Stress – strain curve of ck45 steel

In order to obtain the chemical composition of steel, quantum test carried out, the results are shown in table below:

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Table 3. Chemical composition of ck45 steel

	Fe	C	Si	Mn	Cr	Ni
(Wt. %)	98.3	0.445	0.261	0.56	0.123	0.085

Figure 3 - grain orientation of rolled steel.

According to the experimental design using by taguchi method, nine test specimens was designed. Figure 4 shows the testing machine and a specimen mounted on it. The specimens are plate with 300mm and 100 mm height and width respectively. The thickness of all specimens is 3mm and the length of initial crack is 20mm. a sinusoidal loading was applied with amplitude of 11.875kN and mean load of 13.125kN with frequency of 5Hz. During the test a microscopic camera with magnification of 100x is used to view the crack growth path. Figure 5 shows crack path in specimen with the circular cutout and initial crack angle of 15 degree.

Figure 4. Testing machine

In the fatigue tests the curve of length of crack vs. number of cycles was calculated. The taguchi analysis criteria is life of steel under fatigue loading that defines as larger is better analysis method. The following table shows life of each specimen in the fatigue test:

Table 4. Fatigue life of specimens

	Fatigue life (Cycle)
Specimen 1	51570
Specimen 2	59150
Specimen 3	56865
Specimen 4	54295
Specimen 5	34265
Specimen 6	36206
Specimen 7	34314
Specimen 8	47041
Specimen 9	32310

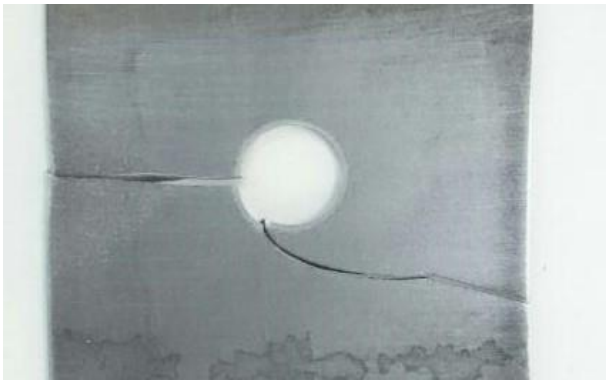

Figure 5 - fatigue crack path in the specimen with circular cutout

According to table 4 can determine the importance of each parameter in the fatigue life of steel.

III. RESULT AND DISCUSSION

In these tests fatigue life of each specimens was listed in table 4. The aim of taguchi analysis is maximize the fatigue life of steel by using different cutouts. Results of the signal to noise ratios charts are shown in figure 6. In figure 6, the chart of signals to noise ratios for four parameters and three levels of each parameter are shown. Based on taguchi analysis, the greater signal to noise ratio for each parameter indicates more effective parameter on the fatigue life of specimen. Signal to noise ratio, priority and importance of each parameter in fatigue life is shown in table 5. According to Table 5 and the difference between the maximum and minimum signal to noise ratio for each parameter, it can be concluded that the initial crack angle is the most parameter in the fatigue life. According to the taguchi analysis the best design for maximize fatigue life, is the design that the parameters of initial crack angle, geometry of cutout, size of crack and

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vertical distance of cutout to edge crack, have levels of horizontal edge crack (0-degree), circular cutout, 20mm and 25 mm respectively so in this case of design, the fatigue life of specimen is equal to 69568 cycles.

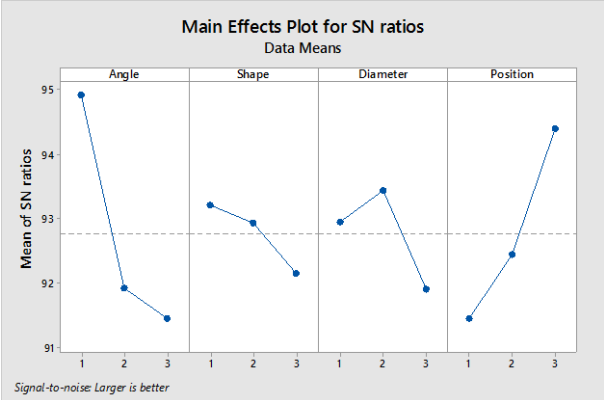

Figure 6 - to noise curve of each parameter

Table 5. Priority of effect of each parameter on fatigue life

Signal to noise ratio	Initial crack angle	Position	Geometry of cutout	Size of cutout
Level 1	95	91.4	93.2	92.95
Level 2	91.85	92.45	92.85	93.4
Level 3	91.4	94.3	92.15	91.4
Delta*	3.6	2.9	2.05	2.05
Priority	1	2	3	4

*delta indicates difference between maximum and minimum value of SN ratio

IV. *Conclusion*

The aim of this study was to evaluate the effect of cutout on the crack path and fatigue life of steel specimens of ck45 steel. For this purpose, the effect of four parameters including initial crack angle, geometry of cutout, size of cutout and vertical distance of cutout to edge crack, on the fatigue life and crack path done by using the taguchi design of experiment analysis. So with taguchi analysis and signal to noise ratio, it determined that crack angle and position of cutout are the most important parameters in fatigue life of steel. Thus focus on these two parameters on the design of components are so important to maximize the fatigue life of steel structures.

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