

# Optimization of Distortion in Welding

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## Abstract

Distortion and residual stresses are two major perennial problems faced by fabrication engineers. The change of shape and dimensions that occur after welding is termed as distortion, leading to various undesirable consequences. So there exists a necessity to control distortion within limits. When distortion exceeds acceptable limits, correction of distortion after the complete fabrication results in major reworking operation that consumes both fabrication time and cost. Distortion control in complex structures has always been a challenge to fabrication engineers, especially to those dealing with ship structures, machinery constructions, railroad, aerospace, pressure vessels, pipes and automotive etc. In order to deal with this problem, it is necessary to predict the specific type and amount of distortion resulting from the welding operations. In such structures, Butt-joints are very common. The angular tilt is predominant in these types of joints. To arrive at an appropriate control method, an in-depth analysis of the shape change deformation behavior of the component and the key factors that influence the distortion are essential. This angular distortion is mainly caused by the non-uniform extension and contraction through thickness direction due to the temperature gradient. Restriction of this distortion by restraints may lead to higher residual stresses. However, if the magnitude of the angular distortion is predictable, these can be reduced by providing initial angular distortion in the negative direction. It is difficult to obtain a complete analytical solution to predict angular distortion that may be reliable over a wide range of processes, materials, and process control parameters. Presently, several analytical methods and empirical formulas have been developed to give quantitative information. In this study, the Taguchi's method of four factors and two levels i.e. L8 array has been used to develop mathematical model to correlate angular distortion in TIG welding. The distortion is found to be significantly influenced by welding current, time gap between successive passes, electrode diameter and length of the work piece. Effects of the process parameters are also analyzed and presented in the graphical form.

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## 1. Introduction

Welding is used extensively in the fabrication of many structures, buildings, ships, pressure vessels, etc., due to many advantages it has, over the other fabrication processes. However, distortion is a problem encountered during welding. The presence of distortion in weldments poses problems in further assembly and in aesthetics. Correcting unacceptable distortion is often costly and in some cases may induce cracking, when improper methods are followed. It is better to control the distortion during welding, through adoption of proper techniques and procedures. The development of proper techniques for reducing and controlling distortion calls for fundamental knowledge on residual stresses, distortion and other factors, which influence them. While welding joins the components of a structure together, the complex thermal cycles from welding result in formation of residual stresses in the joint region, and distortion of the welded structure. Both weld residual stress and distortion can significantly impair the performance and reliability of the welded structures. Distortion in a weld results from the expansion and contraction of the weld metal and adjacent base metal during the heating and cooling cycle of the welding process. During this heating and cooling cycle, many factors affect shrinkage of the metal and lead to distortion.

### Distortion Control

In general, the welder has little influence on the choice of welding procedure but assembly techniques can often be crucial in minimizing distortion. Precautions therefore need to be taken to control this otherwise the welded structure may well be unusable. In general, three basic rules are followed to minimize distortion.

### **Rule 1 - Reduce the effective shrinking force:**

Do not over weld

The use of excessive weld metal over and above that needed to meet the service requirements of the weld is not only wasteful but increases distortion. Ensure proper edge preparation and fit up. This will allow the minimum amount of weld metal to produce a strong joint.

Use few passes

The use of many, small passes increases lateral distortion. Use of fewer passes with a large diameter electrode minimizes lateral distortion.

Place welds near the neutral axis of the device

This concept along with proper sequencing can significantly reduce unwanted distortion. The objective is to make the shrinkage forces exert their influence against each other in order to balance out. In most cases the forces created by shrinking weld metal will act thru the central axis as a fulcrum. The figure 1.4 shows this effect. The left side of the piece is welded which causes the shrinking force as shown by the arrows. The left side is placed under tension and stretches so that the un welded side becomes the long side and the welded side becomes the short side. In the example on the right the forces of the two welds balance out and the assembly remain straight. Keep in mind however that the overall length will be slightly reduced.

This minimizes the effective shrinkage force since the weld does not have sufficient leverage to pull the plates out of alignment.

### **Rule 2 - Make shrinkage forces work to minimize distortion:**

Locate parts out of position. Pre-setting the parts such that the contracting weld metal pulls them into proper alignment when the weld cools is a common way of using the shrinkage of the weld metal to advantage.

Space the parts to allow for shrinkage.

Calculation backed up by experiments will indicate how much space needs to be left for parts to shrink into correct alignment when the weld cools. Pre-bending components may be appropriate so that the contracting weld metal straightens them as it cools.

### **Rule 3 - Balance shrinkage forces with other forces / with another:**

This can often be achieved by adhering to a welding sequence, which places weld metal at different points around the structure so that the shrinkage of one weld counteracts the distortion caused by a previous weld. Peening the weld bead as it cools stretches the weld, thus counteracting its tendency to contract and shrink as it cools. Use jigs and fixtures - the most common method of distortion control, it relies on clamping the work firmly so that the weld is forced to stretch as it cools.

### **Process Parameters affecting angular distortion**

The process input parameters which affect the angular distortion in welding are:

- No of layers on the weld
- Welding speed
- Welding current
- Arc voltage
- Large size electrode
- Joint gap
- Wire feed rate
- Electrode stick out
- Rate of cooling
- Time gap between successive passes.
- Quality of the parent material and electrode.

Here we are considering four factors which have negative significant effect on distortion, these are length of work piece, electrode diameter, time between successive passes and welding current. These four parameters are called Control parameters and the remaining parameters are kept constant, so these are called Constant parameters.

### **Scope of Present Work and Objectives**

In the present work, Taguchi method of design has been adopted to design the experiment and develop a regression equation to solve problems in welding distortion. Four parameters have been selected to study their effect on angular distortion. This work will help to estimate the amount of angular distortion before actually performing the welding.

Proposed regression equation can be used in welding shop to control their output and effectively manage the various parameters during the welding process. It will help save the welding efforts by helping the work done at the first time. Objectives are

- To minimize or optimize the factors that influence angular distortion in TIG welding.
- To develop the mathematical model.
- To analyze the effects of welding parameters

## **Design of Experiment**

### **Introduction**

The appropriate meanings of the word “experiment” as given in Webster’s Dictionary are: “a trial or special observation made to confirm or disapprove something doubtful, especially one under conditions determined by the experimenter; an act or operation undertaken in order to discover some unknown principle or effective or to test, establish, or illustrate some suggested or known truth.” The honor of discovering the idea of design of experiment belongs to Sir Ronald Fisher. Box and Wilson in their paper proposed that an investigator organizes consecutive small no of trials, in each of which all the factors are simultaneously varied according to definite rules. The series are so organized that after mathematical processing of preceding ones it will be possible to further select the conditions for conducting the experiment that is to design the experiment.

The purpose of the theory of design experiment is to ensure that the experimenter obtains data relevant to his hypothesis in as economical a way as possible following a sequential way of analysis. Fisher has summed up the advantage of factorial experiments in that they result in:

- Greater efficiency
- Greater comprehensiveness in that:
- Effects of factors are estimated

### **Taguchi Method**

The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. The Taguchi method is best used when there is an intermediate number of variables (3 to 50), few interactions between variables, and when only a few variables contribute significantly.

### **Taguchi's Loss Function**

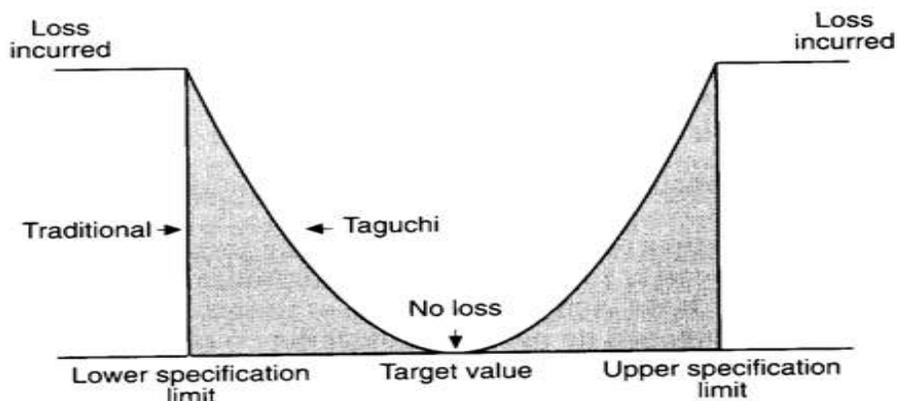
#### **Definition:**

Simply put, the Taguchi loss function is a way to show how each non-perfect part produced, results in a loss for the company. Deming states that it shows

"a minimal loss at the nominal value, and an ever-increasing loss with departure either way from the nominal value." - W. Edwards Deming

A technical definition is:

A parabolic representation that estimates the quality loss, expressed monetarily, that results when quality characteristics deviate from the target values. The cost of this deviation increases quadratically as the characteristic moves farther from the target value. - Duce, William



### Experimental Procedure

The experiments were conducted on mild steel and stainless steel plates of size 100 x 75 x 8 mm and 125 x 75 x 8 mm plates as per the design matrix (Table 3.2). A 30° V-groove was made on each plate so as to make butt joint. Each one of the cleaned plate was welded employing an electrode positive polarity. Weld beads were deposited in the V-groove using Stainless steel wire. The plates were cleaned mechanically to remove oxide layer and any other source of hydrogen, before welding. Weld bead were deposited using a mechanized Tungsten inert gas (TIG) machine to ensure the reproducibility of the data. This also eliminated the effects of welder's skill on the result.

Parameters	Symbols	Units	Limits	
			Low(-1)	High(+1)
Length	l	mm	100	125
Dia.	d	mm	1.5	2
Time between passes	t	Min.	0	5
Welding Current	c	Amp	70	90

The complete sets of eight trials were repeated once to determine the 'variance of optimization parameters' for the model. The experiments were performed in a random order to avoid any systematic error.

### Results and Discussions

#### Design array with experimental values of distortion

S.no	l	d	t	C	Distortion	S/N Ratio
	1	2	3	4		
1	-	-	-	+	7.235 <sup>0</sup>	-17.1888
2	-	-	+	-	3.624 <sup>0</sup>	-11.1838
3	-	+	-	-	5.671 <sup>0</sup>	-15.0732
4	-	+	+	+	6.913 <sup>0</sup>	-16.7933
5	+	-	-	-	4.169 <sup>0</sup>	-12.4006

6	+	-	+	+	4.621 <sup>0</sup>	-13.2947
7	+	+	=	+	6.331 <sup>0</sup>	-16.0294
8	+	+	+	-	3.845 <sup>0</sup>	-11.6979

Table 5.1: Design Matrix with Distortion Values

**Mathematical model**

.....(a)

From the Regression analysis, we got the values for the above coefficients as:

Serial No.	Coefficient	Values of Coefficient
1	b <sub>0</sub>	0.37
2	b <sub>1</sub>	-0.0448
3	b <sub>2</sub>	1.56
4	b <sub>3</sub>	-0.220
5	b <sub>4</sub>	0.0974

Table 5.2: Calculated values of Coefficients

By putting the values of various parameters, we found the theoretical values of the distortion for various set of design parameters.

**Regression Results**

Predictor	Coef	SE Coef	T	P
Constant	0.375	1.994	0.19	0.863
l	-0.04477	0.01139	-3.93	0.029
d	1.5555	0.5697	2.73	0.072
t	-0.22015	0.05697	-3.86	0.031
c	0.09739	0.01424	6.84	0.006

S = 0.402822 R-Sq = 96.6% R-Sq(adj) = 92.0%

**Conclusions**

The following conclusions were arrived at from the above investigation:

- The Taguchi's design of orthogonal arrays can be employed easily for developing mathematical model for optimizing the distortion within the workable region of the control parameters like length of work piece, diameter of electrode, time gap between successive passes and welding current in Tungsten arc welding.
- Angular distortion decreases with the increase in length within the design range of parameters.
- With the increase in electrode diameter, the angular distortion increases within the design range of parameters.

- Angular distortion decreases with the increase in time gap between successive passes within the design range of parameters.
- With the increase in current, the angular distortion increases within the design range of parameters.
- The process parameter current has the highest effect on angular distortion.
- Within the design range of parameters, the least effect on angular distortion is found of diameter of electrode.
- The angular distortion is minimum when the length of plate is 125, electrode diameter is 1.5 mm, time between successive passes is 5, and welding current is 70 amp.

The optimum value of angular distortion is  $2.828^0$ .

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