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Identification of Factors Influencing the Thickness of Bonding of Titanium Alloy Sheets Using Taguchi Method

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Abstract

For the processing and forming of two titanium alloy sheets of the same thickness, because of the high requirement for thickness precision, how to use the equipment to control the diffusion bonding characteristics so that the finished product can achieve the target value of the overlap thickness. Using the Taguchi method for parameter design, experiments were conducted using the L9 (3^4) orthogonal table to investigate the effect of four process conditions of temperature, pressure, time, and cleanliness on thickness. Among them, the temperature has the most significant influence on the thickness target and the optimized process condition parameters are obtained.

Keywords

Taguchi method; Titanium; Thickness.

1. Introduction

For the processing and forming of titanium alloy, the leading countries are currently using thermo forming method, the strength of the material will be reduced at high temperature, and the ductility will be increased. Also, the resilience and the minimum bending radius will decrease rapidly with the increase of temperature and the increase of molding time, which makes it easier to shape the workpiece, and to control the accuracy and quality. Among the thermo forming technologies, the most widely used is the Superplastic Forming (SPF) technology. Diffusion Bonding (DB) is a high level bonding technology that uses materials with a good diffusion effect under high temperature and pressure to bond two materials together. [1] [2] The temperature of superplastic forming is similar to that of diffusion bonding. If these two technologies are combined, the SPF/DB can be used to achieve a one-piece structure for complex and irregular components. It can effectively reduce the number of parts and joints, which not only saves weight to achieve the purpose of light weight, but also improves the overall structural strength and rigidity. In order to respond to the rapid changes in the market and industrial environment nowadays, companies are making every effort to pursue various ways to save the cost and time of experiments. It is best to be able to analyze the factors affecting the thickness of two identical materials after fusion without the need for a large number of samples. Through data processing, their correlation, main characteristics and main influencing factors are identified. And it is hoped that the relationship between parameters can be quickly and effectively identified, so that we can quickly respond to market demand.

2. Literature Review

The Taguchi method is used to improve the quality of products and processes by measuring quality at the time of product or process design in order to understand and establish quality in the process beforehand. The Taguchi method uses orthogonal-array (OA) to design experiments to reduce cost and process variation. The metric that determines the quality of the measurement of the best combination of standards is the Signal-Noise Ratio (SN Ratio). Dr. Genichi Taguchi divides quality engineering into three stages: system design, parameter design,

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and tolerance design, of which parameter design is the largest contributor advocated by Dr. Taguchi. The parameters affecting the quality characteristics are divided into three categories: control factor, signal factor, and noise factor, which are described as follows [5]. (1) Control factor: Its level is controlled and determined by the designer to minimize the quality loss. (2) Signal factor: It is set by the user or operator of the product to express the desired response value. (3) Noise factor: A parameter beyond the control of the designer is called the noise factor, and the level varies with the environment. The traditional concept of quality is that no loss occurs when the quality characteristics of the product deviate from the target value but fall within the specification limits. However, Dr. Taguchi Genichi believed that as long as the quality characteristics of a product deviate from the target value, it is considered as a loss of quality. He also advocated the concept of quality loss to measure the quality of a product, whose loss function is proportional to the square of the amount by which the product quality deviates from the target value. Based on the type of quality characteristics, there are three categories. 1. Nominal the best: the closer the measured value of product quality characteristics to the target value, the better; 2. Smaller the best: the smaller the measured value of product quality characteristics, the better. The ideal value is zero, but shall not be a negative number. 3. Larger the best: the larger the measured value of product quality characteristics, the better. The ideal value of ∞. The signal to noise ratio is defined as η = log (the strength of the signal / the strength of the noise) db, where the signal is defined as S (signal), the noise is defined as N (noise), and the signal to noise ratio is defined as S / N ratio. [3]

Dr. Taguchi believed that good quality must be consistent with the average value of quality characteristics and the target value, and the smaller the variation, the better. By using this definition, he created the S/N ratio used in "Robust Design", which defines "useful signal" as the average value of product quality characteristics, and the closer the value to the target value, the better. Then, "harmful signal" represents the measured value of product quality characteristics variation, and the smaller the value, the better. When the S/N ratio is used to measure the stability of quality, the higher the S/N ratio, the more stable the quality and the lower the expected loss. On the contrary, the lower the S/N ratio, the more unstable the quality and the higher the expected loss, so the S/N ratio is an indicator of good or bad process or product quality. The ideal S/N ratio should have the following properties. (1) The S/N ratio should reflect the variability of the quality characteristics. (2) The S/N ratio should be independent of the mean adjustment, so that when the target value changes, the S/N ratio can still be used to predict the quality. (3) The S/N ratio should measure the relative quality because it is intended for comparison. And (4) the S/N ratio should be simple and additive. In order to reduce the influence of product quality by noise factors in order to find the best combination of control factors under various noise factors to reduce the variability of product quality, the method is validated by using an orthogonal table, aiming at using a small number of experiments in order to obtain the desired results. The so-called orthogonal means balanced or divisible, and orthogonal between the levels of each factor, meaning that the combination of each level must exist and the number of occurrences should be equal. That is, the effects of each factor are separable, and the experimental results can be safely compared.

After the configuration of the factors of orthogonal table is completed, the experiments can be conducted according to the experimental combinations planned in the orthogonal table and the experimental data can be collected. When the data are collected, the user can draw a response table or response graph of the S/N ratio or the mean value to indicate the best combination of the decision parameters and to estimate their mean values. Forming methods that uses the properties of materials under certain conditions (temperature, deformation rate, and organization, etc.) are used to form components or mold types by large deformation processing. The following forming methods are currently used in industry.

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1.BlowForming.2.VaccumForming.3.SPF/DB.4.ThermoForming.5.DeepDrawing.6.Forging.7.Extrusion.8.Dieless Drawing.

Each of the above eight forming methods has its own unique ability and formability. At present, the blow forming method is the most popular one used in industry. The material has low resistance to deformation in the superplastic state and has excellent plasticity, and can be formed by blowing like glass and plastic, which is commonly used to produce thin shell parts with the most common feature of simple technology and equipment. The superplastic behavior of a material is strongly influenced by the constant m. When m is at least higher than 0.3, the material can be considered to have superplasticity. If the value of m is close to 1, the material has a high elongation and high superplastic material behavior. Theoretically, any material with a stable fine crystal structure (generally less than 10 μm) at constant temperature can be molded by the SPF process. Ti-6Al-4V alloy: (a) Ti-6Al-4V has very good superplasticity forming and diffusion bonding characteristics. The superplastic forming temperature is about 925°C. If the temperature exceeds the β metastable point (about 980°C), it will cause β single phase and rapid grain growth, which will deteriorate the superplastic properties. (b) The temperature of diffusion bonding is similar to that of superplastic molding, and the diffusion bonding should be protected by argon gas to avoid the formation of an oxide layer that will prevent the diffusion bonding process. (c) The diffusion bonding temperature is similar to that of superplastic forming, and the two processes can be performed under one thermal cycle. [4]

3. Methodology

After the key factor X is determined, Taguchi experiments are conducted and the results are analyzed for variance in order to determine the contribution of each factor and finally to find the best combination of parameters. The design of parameters in Taguchi's quality engineering is divided into three major stages: planning of the experiment, execution of the experiment, and analysis and confirmation of the experimental results. To confirm the best combination of parameters, the optimized parameters are extrapolated to the predicted S/N ratio. Finally, a statistical check is made to confirm that the process problems are significantly improved at a 95% confidence level. In superplastic forming, in addition to holes, cracks can easily occur if the parameters of temperature, pressure and strain rate are not set properly. In order to improve the production efficiency of the workpiece, the workpiece is generally taken out immediately after forming at high temperature, thus there will be a surface oxidation layer, which can be removed by the chemical mill method. However, diffusion bonding technology and SPF/DB composite processing technology, diffusion bonding process, the initial contact between the plate and the plate material for point contact. After high temperature blowing and pressure, it becomes surface contact, but there are still a small number of holes (1st step). After a period of grain growth and diffusion to eliminate the holes, it is finally completely tight bonding through the bulk diffusion.

SPF/DB composite processing technology is a combination of superplastic forming and diffusion bonding technology to complete the one-piece hollow structure. For 3-layer SPF/DB, the stop-off is only applied to the middle part of the sheet where no bonding is required and to the contact surface between the two ends of the sheet and the mold. For SPF/DB of 4-layer sheet, the joint design is very important. The flow inhibitor should be applied at the place where it is not necessary to join, and the amount of application should be controlled, not too much to avoid flowing to the place where it is to be joined. And the part which is in contact with the mold should be fully coated to avoid the difficulty of taking out the workpiece by joining the workpiece with the mold. SPF/DB composite processing technology is more complex and difficult in the process operation, mold design, workpiece design, gas piping design and processing process parameters are very important. In addition, the flatness and roughness of

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the workpiece joint surface requirements and the workpiece cleaning and atmosphere protection also need special care. Therefore, the important factors affecting diffusion bonding are as follows: 1. the pressure of the supplied gas, 2. the temperature and time of diffusion bonding, 3. the design of the joints and the use of flow inhibitors, and 4. the surface flatness and cleanliness of the sheet.

Table 1. Control factor level table

Factor	Description	Level 1	Level 2	Level 3
A	Pressure/(kg/cm2)	150	160	170
B	Temperature/℃	900	925	950
C	Time/Sec.	10	20	30
D	Cleanliness/%	85	90	95

4. Empirical Analysis

Two pieces of titanium alloy with a thickness of 20 mm were bonded by diffusion bonding, and four sets of samples were put into the furnace each time. 9 experiments were conducted in total. After completing the experiments, the samples were taken out to measure the thickness after bonding, and the data were shown in Table 2.

Table 2. Orthogonal Arrays and Date

Number	A	B	C	D	Y1	Y2	Y3	Y4
1	150	900	60	85	3.923	3.913	3.933	3.926
2	150	925	120	90	3.955	3.922	3.942	3.939
3	150	950	180	95	3.923	3.912	3.938	3.934
4	160	900	120	95	3.935	3.932	3.937	3.931
5	160	925	180	85	3.957	3.934	3.935	3.942
6	160	950	60	90	3.932	3.942	3.932	3.952
7	170	900	180	90	3.922	3.952	3.931	3.941
8	170	925	60	95	3.958	3.955	3.959	3.937
9	170	950	120	85	3.923	3.953	3.928	3.934

Using the minitab software to calculate the larger the better characteristics. The larger the measured value of the product quality characteristics, the better, and the ideal value is ∞. The values are calculated as shown in Table 3.

Table 3. The Larger The Better SIGNAL-NOISE RATIO

level	A	B	C	D
1	11.89	11.89	11.91	11.9
2	11.91	11.92	11.9	11.91
3	11.91	11.9	11.9	11.9
Delta	0.02	0.03	0.01	0.01
Rank	2	1	4	3

Using minitab software to calculate the average value, the quality must be consistent with the average value of the quality characteristics. The smaller the variation, the better. The values are calculated as shown in Table 4.

Table 4. The average value

level	A	B	C	D
1	3.93	3.931	3.938	3.933
2	3.938	3.945	3.936	3.938
3	3.941	3.934	3.935	3.938
Delta	0.011	0.013	0.003	0.005
Rank	2	1	4	3

The standard deviation is calculated using minitab software, and the values are calculated as in Table 5.

Table 5. Standard Deviation

level	A	B	C	D
1	0.011193	0.007993	0.009395	0.01068
2	0.007648	0.0115	0.009819	0.01203
3	0.012119	0.011468	0.011746	0.00825
Delta	0.004472	0.003507	0.002352	0.00377
Rank	1	3	4	2

The standard deviation factor is plotted using minitab software as shown in Figure 1.

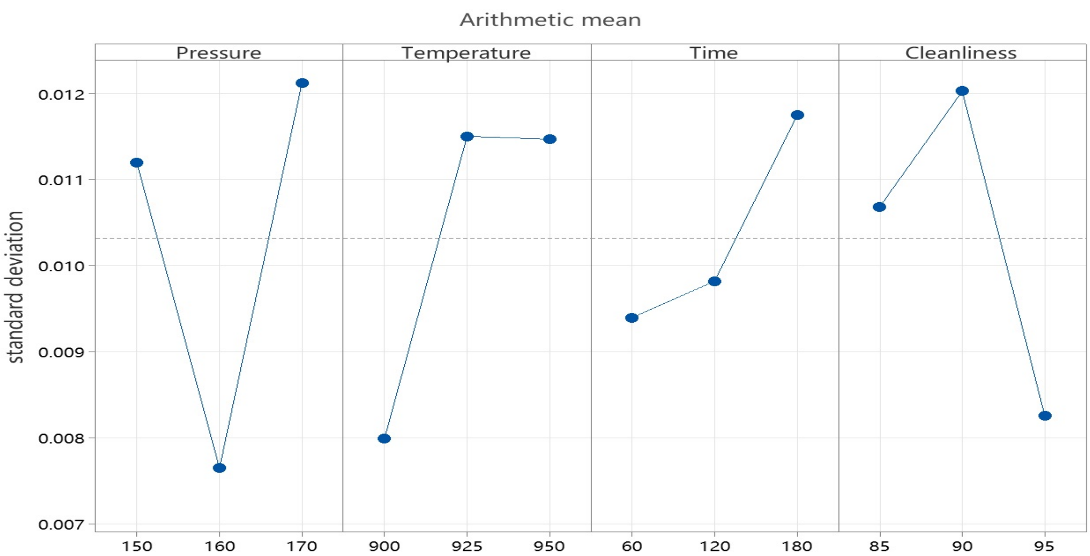

Figure 1. Standard Deviation Factorial Plot

The minitab software is used to plot the mean factor graph as shown in Figure 2.

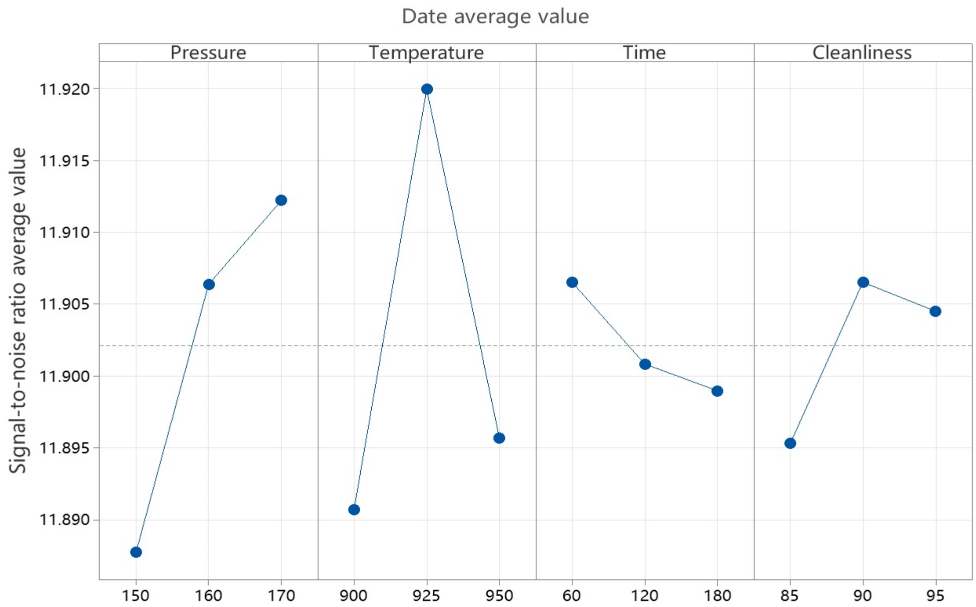

Figure 2. The average value Factorial Plot

5. Conclusion

In this study, it was found that the L9 (3^4) direct cross-tabulation matrix was designed according to the parametric design of experimental method proposed by Taguchi. The process condition factors of the experiment are tabulated as follows. Pressure is A, Temperature is B, Time is C, and Cleanliness is D. The four factors of operation: pressure, temperature, time, and cleanliness are used as key factors, and the implementation process can be divided into the following ten steps. 1. Select the quality characteristic. 2. Determine the ideal function of the quality characteristic. 3. List all the factors affecting the quality characteristic. 4. Determine the level of the signal factor. 5. Determine the level of the control factor. 6. Determine the level of the interference factor and, if necessary, conduct interference tests. 7. Select the appropriate direct cross table and arrange a complete experimental plan. 8. Execute the experiment and record the experimental data. 9. Analyze the data. 10. Repeat the above steps until the best quality and performance are achieved. The quality level is measured as shown in the previous chart, and the ranking is B > A > C > D, which means that B is the best quality level. On the basis of the above, the process is close to the target value, and the process conditions are optimized with minimum variation. In other words, the temperature control will be the focus in the future. The process conditions can be optimized quickly and effectively in the existing system to reduce the waste of money and time, shorten the development cycle, and gain a leading opportunity in the market with fierce competition.

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