CASE 31

Optimization of Two-Piece Gear Brazing Conditions

Abstract: Bonding is indispensable in automobile manufacturing for a wide variety of component parts. Today, brazing is not used often because of its insufficient strength and variability, although the process is very suitable for mass production, The improvement in the brazing process toward higher strength would make the process much more applicable in manufacturing. Here we introduce a two-piece gear brazing experiment to find a robust condition for stable, high-strength joints.

1. Introduction

A two-piece gear consists of two parts. After charging a circular brazing material in a groove of gear 2, we press-fit gear 1 to gear 2 and braze them together in a furnace. Figure 1 outlines the brazing process.

Good brazing that can result in constant strength needs to have the state in which the brazing material is permeated all over the brazing surface. In other words, it should ideally have the same characteristics as that of a one-piece gear. As shown in Figure 2, when pressure is applied, a one-piece gear is supposed to have proportionality between the load and the displacement, following Hooke's law within the elastic range. Therefore, to establish the proportionality between the load, y, and the displacement, M, regardless of gear size, we select the proportionality between them and the proportionality between the load and the brazing area, M^*, as the generic function of brazing.

As signal factors, the displacement, M, and brazing area, M^*, were chosen according to the strength standard and preliminary experimental results, as illustrated in Table 1. On the other hand, as a noise factor, temperature (Table 1) was chosen because the variability in temperature inside the brazing furnace greatly affects brazing permeation.

The experiment was performed according to the pulling strength test shown in Figure 3, and the test piece used had a three-level sectional area with a constant length of a and b (Figure 4) such that the combined area of its vertical and horizontal brazing areas was proportional to the gear diameter, d, resulting in the same amount of brazing material in a unit area.

2. SN Ratio and Sensitivity

According to the measurements obtained by means of the strength test, by using the displacement curve we observed each load for each displacement. Table 2 shows the data of experiment 1 in an L_{18} orthogonal array. Based on these data, we calculated the SN ratio and sensitivity. The table shows the computation procedure.

Total variation:

$$S_T = 0.00^2 + 0.13^2 + \cdots + 7.33^2 + 0.00^2$$
$$= 99.3 \qquad (f = 24) \tag{1}$$

Effective divider:

$$r = [(0.1)(554)]^2 + [(0.1)(679)]^2 + (0.1)(804)]^2 + \cdots + [(0.4)(804)]^2$$
$$= 423{,}980 \tag{2}$$

Variation of proportional terms:

 Taguchi's Quality Engineering Handbook. Genichi Taguchi, Subir Chowdhury and Yuin Wu

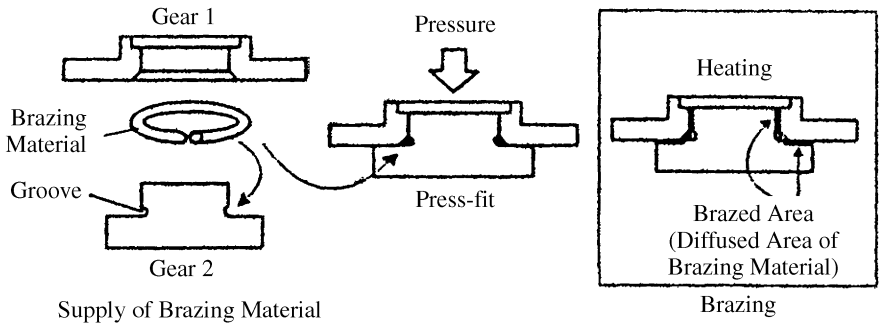

Figure 1
Gear brazing process

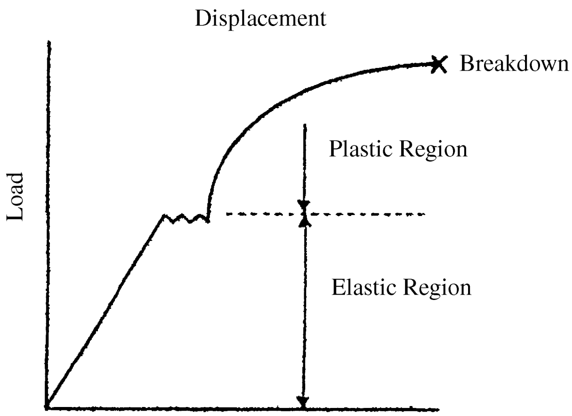

Figure 2
Material property of a one-piece gear

$$S_\beta = \frac{1}{2r}\left[\begin{array}{l}(0.1)(554)(0.00 + 0.13)\\ + (0.1)(679)(0.1 + 0.005)\\ + \cdots + (0.4)(679)\\ (0.00 + 0.00) + (0.4)(804)\\ (7.33 + 0.00)\end{array}\right] = 24.54 \qquad (f = 1) \tag{3}$$

Variation of differences of proportional terms:

$$S_{N\beta} = \frac{1}{r}\left[\begin{array}{l}(0.1)(554)(0.00)\\ + \cdots + (0.4)(804)(733)^2\\ + (0.1)(554)(0.13)\\ + \cdots + (0.4)(804)(0.00)^2\end{array}\right] - 24.54 = 22.61 \qquad (f = 1) \tag{4}$$

Error variation:

Table 1
Signal and noise factors and levels

Factor	Level 1	2	3	4
Signal factors				
Displacement, *M* (mm)	0.1	0.2	0.3	0.4
Brazing area, *M** (mm^2)	554	679	804	—
Noise factor				
Furnace temperature, *N*	High	Low	—	—

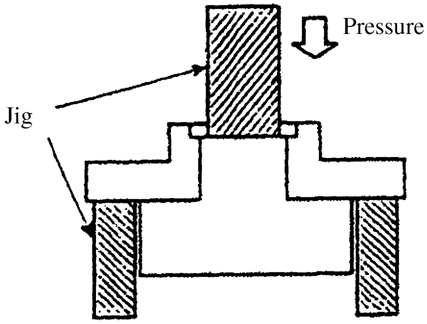

Figure 3
Testing method for a two-piece gear (pulling strength test)

$$S_e = S_T - S_{N\beta} - S_\beta = 52.15 \qquad (f = 22) \qquad (5)$$

Error variance:

$$V_e = \frac{S_e}{22} = 2.370 \qquad (6)$$

Total error variance after pooling:

$$V_N = \frac{S_{N\beta} + S_e}{23} = 3.25 \qquad (7)$$

SN ratio:

$$\eta = 10 \log \frac{(1/2r)(S_\beta - V_e)}{V_N} = -50.95 \text{ dB} \qquad (8)$$

Sensitivity:

$$S = 10 \log \frac{1}{2r}(S_\beta - V_e) = -45.83 \text{ dB} \qquad (9)$$

3. Optimization and Results of Confirmatory Experiment

Table 3 shows the control factors selected. After choosing factors regarding material and shape that affect the permeation of brazing material, we assigned each of the initial conditions to level 2 and varied it with a large range as levels 1 and 3. Figure 5 summarizes the response graphs. In addition, we performed confirmatory experiments at both the

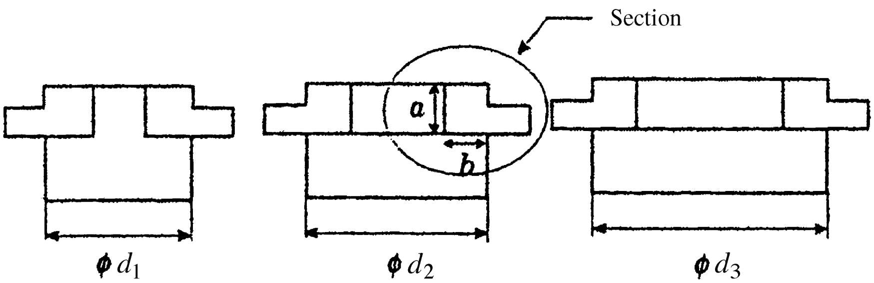

Figure 4
Test piece shape of a two-piece gear

Table 2
Strength test measurements

	M_1 (0.1 mm)			M_2 (0.2 mm)			M_3 (0.3 mm)			M_4 (0.4 mm)		
	M_1^*	M_2^*	M_3^*	M_1^*	M_2^*	M_3^*	M_1^*	M_2^*	M_3^*	M_1^*	M_2^*	M_3^*
N_1	0.00	0.10	2.08	0.00	0.23	3.55	0.00	0.25	5.33	0.00	0.00	7.33
N_2	0.13	0.05	0.00	0.15	0.08	0.00	0.20	0.10	0.00	0.00	0.00	0.00

Table 3
Control factors and levels

Control Factor		Level 1	Level 2	Level 3
A:	flux supply position	Bottom	Top	—
B:	flux concentration	Thin	Med.	Concentrate
C:	amount of flux	Less	Med.	More
D:	amount of brazing material	Less	Med.	More
E:	amount of melting-point-lowering material	Less	Med.	More
F:	roughness of contacting surface	Fine	Med.	Rough
G:	tighting amount	Small	Med.	Large
H:	pressure	Low	Med.	High

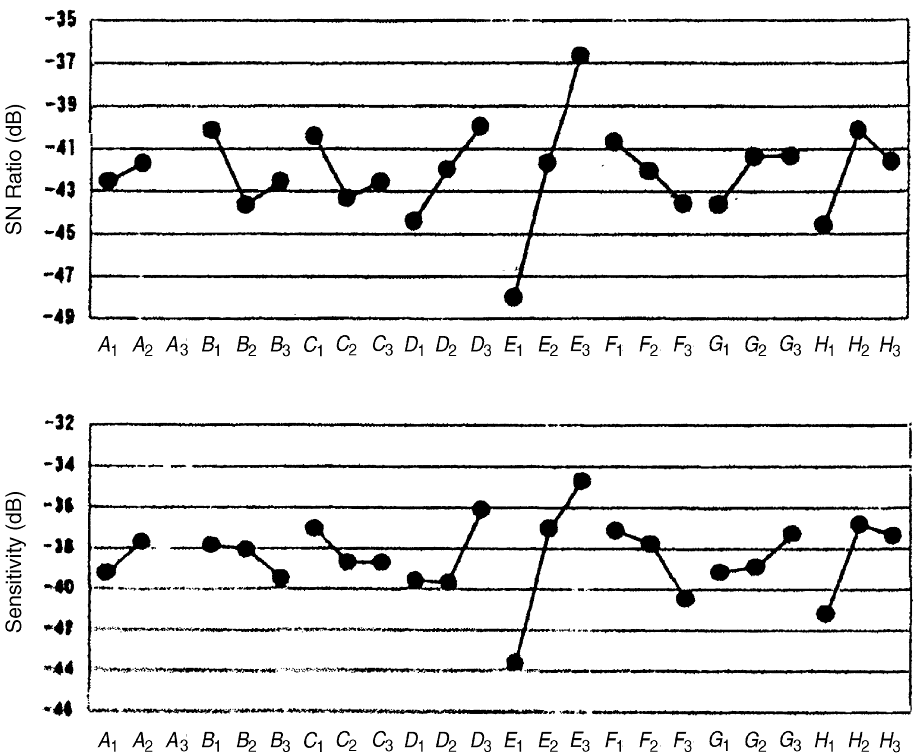

Figure 5
Response graphs

Table 4
Estimation and confirmation of SN ratio and sensitivity (dB)

	SN Ratio		Sensitivity	
Configuration	**Estimation**	**Confirmation**	**Estimation**	**Confirmation**
Optimal	−34.5	−36.0	−32.4	−30.7
Initial	−41.6	−43.4	−38.3	−34.6
Gain	7.1	7.4	5.9	3.9

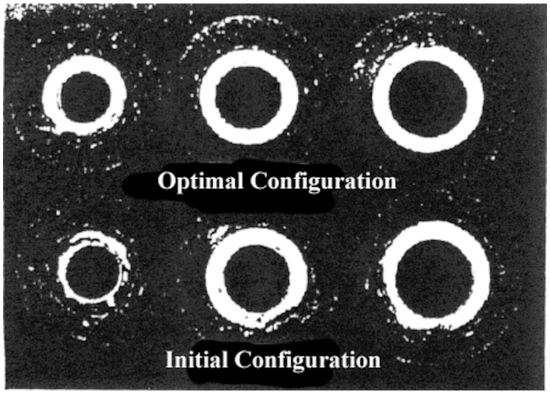

Figure 6
Ruptured section of brazing area

optimal and initial conditions. The results are outlined in Table 4.

For the SN ratio, a gain of 7.4 dB and good reproducibility were obtained. For the sensitivity, a somewhat smaller gain of 3.9 dB but sufficient reproducibility were earned. These results are confirmed in a photograph of the ruptured section (Figure 6), which indicates that brazing material is diffused all over the circumference, regardless of the brazing area size under the optimal configuration, whereas there exists a portion with no brazing material diffused under the initial configuration.

Converting 7.45 dB into a nondecibel number, we have

$$\mu^* = 10^{0.745} = 5.55 \tag{10}$$

Then the error variance of 1/5.55 is the initial configuration. Applying this result to an actual product, we obtain the histogram in Figure 7, based on a torsion test to evaluate the original function of a gear. This reveals that we can improve both the variability and strength under the optimal configuration as compared with those under the initial configuration.

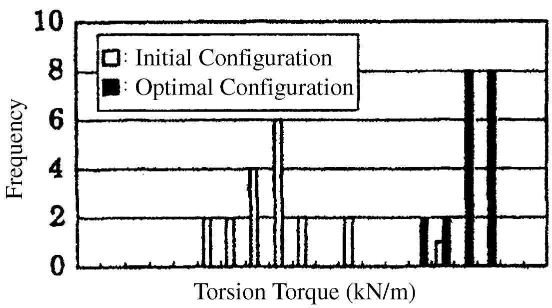

Figure 7
Result of torsion test

Reference

Akira Hashimoto, 1997. Optimization of two-piece gear brazing condition. *Quality Engineering*, Vol. 5, No. 3, pp. 47–54.

This case study is contributed by Akira Hashimoto.