CASE 33

Tile Manufacturing Using Industrial Waste

Abstract: In this study we performed experiments based on the generic function of tile manufacture, forming a tile with evenly distributed density with the intention of saving on material in order to avoid waste. As a signal factor and output, we selected weight in the air and weight in the water and measured the proportionality of an underwater weight to an in-the-air weight.

1. Generic Function

We filled a press die evenly with material, that is, formed a tile with evenly distributed density. Then, as a signal factor and output, we selected a weight in the air and a weight in the water, respectively, and measured the proportionality of underwater weight to in-the-air weight. To measure the underwater weight, we attempted to use underwater weighing. Although it was not easy to calculate the underwater weight of a absorptive tile, we were able to do so through our technical know-how.

In actuality, we split a formed tile into several pieces, as shown in Figure 1*a*, and defined $y = \beta M$ as the ideal relationship equation of the in-the-air weight, M, and the underwater weight, y, according to Figure 1*b*. In addition, since we know that to measure the geometric dimensions of a formed tile and to judge its appearance are relatively easy, for the purpose of fundamental research we checked the transformability of its shape and appearance. As illustrated in Figure 2, setting the dimensions of a die to a signal factor, M, and each corresponding dimensions of a formed tile to y, we defined $y = \beta M$ as the ideal relationship equation. A caliper was used for measurement.

On the other hand, since a tile that is not easily separated from the base plate after being baked tends to have a poor surface, we performed a smaller-the-better analysis by setting the value of an easily separated tile to 0, that of a not-easily separated tile to 100, and that of a tile in between to 50. For noise factors, we select the following four:

1. Baking temperature, N (two levels)
2. Major row materials maintaining conditions, N^* (two levels)
3. Drying condition of mixture of sand and water, N^{**} (two levels)
4. Tile thickness, N^{***} (two levels)

As an analysis example, we showed the analysis of in-the-air versus underwater weights. Table 1 shows the data examples and the calculation process.

Total variation:

$$S_T = 5.40^2 + 2.81^2 + \cdots + 0.48^2 = 468.8553 \quad (f = 80) \tag{1}$$

Effective divider:

$$r_1 = 12.91^2 + 6.87^2 + 3.81^2 + 1.78^2 + 1.73^2 = 234.5424 \tag{2}$$

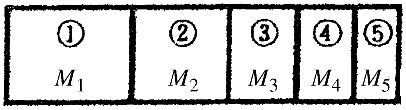
Total of effective dividers:

$$r = r_1 + r_2 + \cdots + r_{16} = 3080.1503 \tag{3}$$

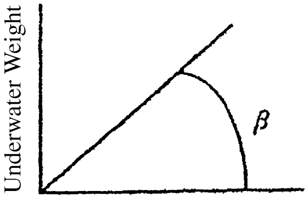
Variation of proportional term:

$$S_\beta = \frac{(L_1 + L_2 + \cdots + L_{16})^2}{r} = 459.9931 \quad (f = 1) \tag{4}$$

Variation of sensitivity:



(*a*) Division of baked tile



(*b*) Relationship between in-the-air weight and underwater weight

Figure 1
Proportionality of divided tile

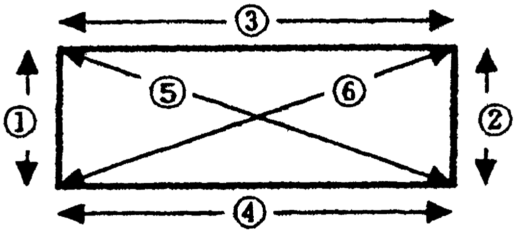


Figure 2
Measurement of tile's dimensions

Table 1
Data examples of in-the-air and underwater weights (experiment 1)

					M_1	M_2	M_3	M_4	M_5
N_1	N_1^*	N_1^{**}	N_1^{***}	In-the-air weight	12.91	6.87	3.81	1.78	1.73
				Underwater weight	5.40	2.81	1.59	0.76	0.72
			N_2^{***}	In-the-air weight	10.61	4.58	2.72	1.48	1.25
				Underwater weight	4.40	1.87	1.13	0.62	0.58
		N_2^{**}	N_1^{***}	In-the-air weight	12.85	6.62	3.23	2.04	1.53
				Underwater weight	5.86	3.00	1.44	0.92	0.70
			N_2^{***}	In-the-air weight	11.06	6.74	3.52	1.56	1.29
				Underwater weight	4.98	3.08	1.59	0.72	0.60
	N_2^*	N_1^{**}	N_1^{***}	In-the-air weight	11.92	7.15	3.89	2.20	1.36
				Underwater weight	3.65	2.12	1.15	0.69	0.56
			N_2^{***}	In-the-air weight	10.24	5.43	3.05	1.80	1.13
				Underwater weight	3.04	1.56	0.92	0.48	0.33
N_2	N_2^*	N_1^{**}		In-the-air weight	3.69	2.13	0.97	0.68	0.44
			N_2^{***}	In-the-air weight	10.64	5.69	2.58	1.56	1.01
				Underwater weight	3.70	1.93	0.99	0.67	0.38
		N_2^{**}	N_1^{***}	In-the-air weight	12.17	6.88	3.27	1.85	1.60
				Underwater weight	4.33	2.39	1.19	0.70	0.62
			N_2^{***}	In-the-air weight	9.98	5.24	2.43	1.45	1.30
				Underwater weight	3.73	1.88	0.92	0.51	0.48

Table 2
Control factors and levels

	Control Factor	Level 1	Level 2	Level 3
A:	pulverizing time	Long	Short	—
B:	pressing pressure	Small	Mid	Large
C:	clay 1 (%)	5	10	15
D:	waste 1 (%)	0	3	6
E:	waste 2 (%)	0	3	6
F:	waste 3 (%)	10	15	20
G:	waste 4 (%)	10	15	20
H:	clay 2 (%)	0	2	4

$$S_{\beta N} = \frac{(L_1 + \cdots + L_8)^2}{r_1 + \cdots + r_8} + \frac{(L_9 + \cdots + L_{16})^2}{r_9 + \cdots + r_{16}} = 2.1038 \qquad (f = 1) \tag{5}$$

$$S_{\beta N*} = \frac{(L_1 + L_2 + L_3 + L_4 + L_9 + L_{10} + L_{11} + L_{12})^2}{r_1 + r_2 + r_3 + r_4 + r_9 + r_{10} + r_{11} + r_{12}} + \frac{(L_5 + \cdots + L_{16})^2}{r_5 + \cdots + r_{16}} - S_\beta = 6.8997 \qquad (f = 1) \tag{6}$$

Similarly,

$$S_{\beta N**} = 1.6786 \qquad (f = 1) \tag{7}$$

$$S_{\beta N***} = 0.0035 \qquad (f = 1) \tag{8}$$

Error variation:

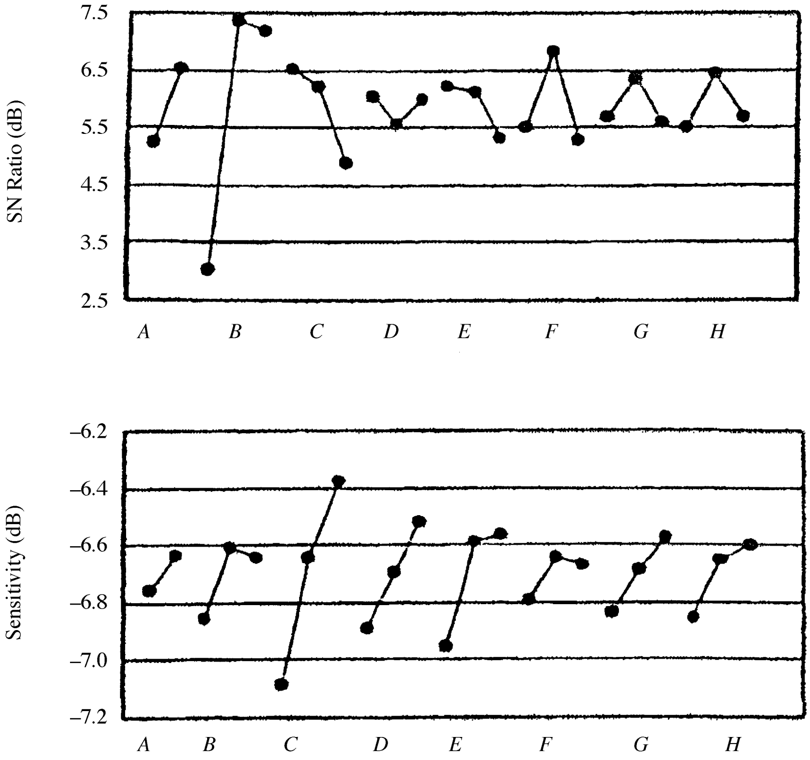


Figure 3
Response graphs of in-the-air versus underwater weights

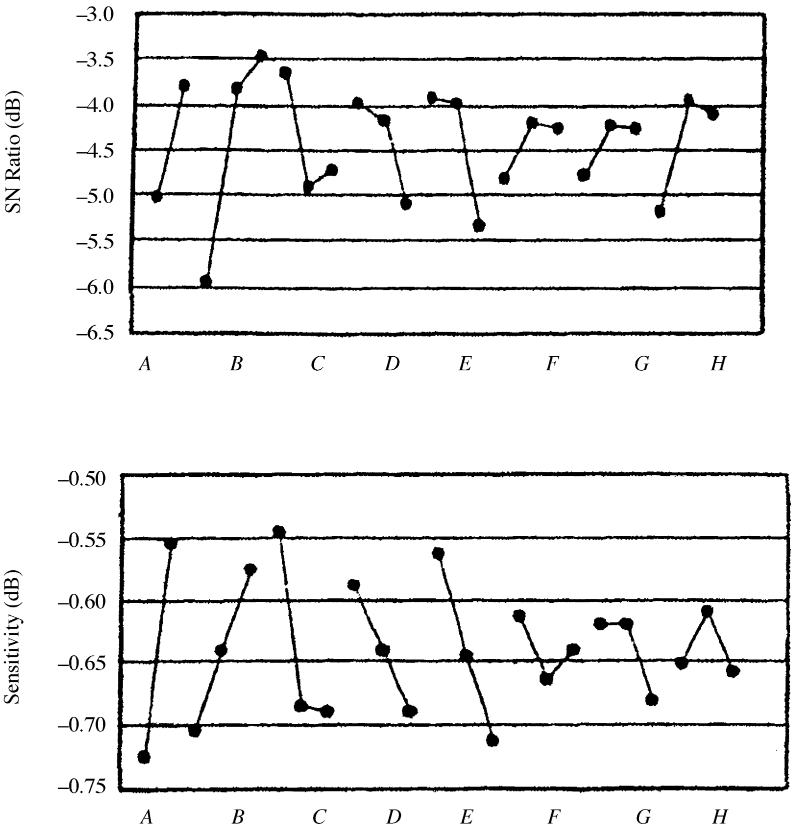


Figure 4
Response graphs of shape transformability

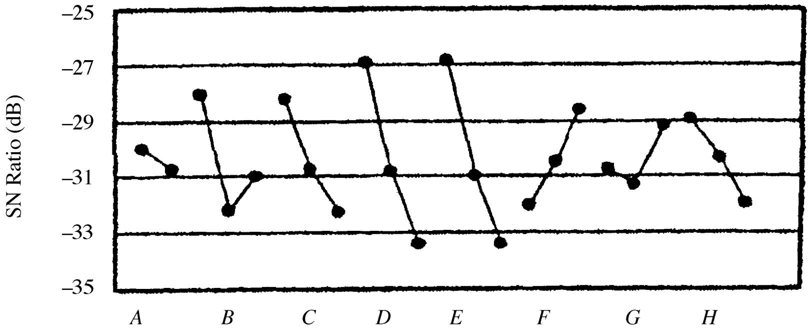


Figure 5
Response graph of separability

Table 3
Optimal and compared configurations

	Factor							
	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*
In-the-air weight Underwater weight	2	2 3	1	(1)	1	(2)	(2)	(2)
Transformality of shape	2	3	1	(1)	1	(2)	(2)	(2)
Appearance	(1)	1	1	1	1	3	(3)	1
Optimal configuration	2	3	1	(1)	1	(3)	(3)	(2)
Compared configuration	1	1	2	(2)	3	(2)	(3)	(1)

$$S_e = S_T - S_\beta - S_{\beta N} - S_{\beta N^*} - S_{\beta N^{**}} - S_{\beta N^{***}}$$

$$= 0.2641 \qquad (f = 75) \tag{9}$$

Error variance:

$$V_e = \frac{S_e}{75} = 0.0035 \tag{10}$$

Compounded error variance:

$$V_N = \frac{S_e + S_{\beta N} + S_{\beta N^*} + S_{\beta N^{**}} + S_{\beta N^{***}})}{79}$$

$$= 0.1122 \tag{11}$$

SN ratio:

$$\eta = \frac{(1/r)(S_\beta - V_e)}{V_N} = 1.3312 = 1.24 \text{ dB} \tag{12}$$

Sensitivity:

$$S = \frac{1}{r}(S_\beta - V_e) = 0.1493 = -8.26 \text{ dB} \tag{13}$$

2. Control Factors and Experimental Results

Table 2 shows the control factors selected for our study. Now we assign to an L_{18} orthogonal array factors related primarily to material mixture. For major industrial wastes, we mix them using the following equation:

$$100 - C - D - E - F - G - H\ (\%)$$

Figure 3 shows the response graphs of the SN ratio and sensitivity for underwater versus in-the-air weights. When the filling density is high, the sensitivity becomes large. Figure 4 shows the response graph of the transformability of shape. Now, for the analysis of shape, among 18 experiments in total, the tiles used in experiments 6, 12, and 14 cannot be separated from the base plate. Therefore, we handled the columns of these three experiments as missing values, and by substituting the averages of the SN ratio and sensitivity as a provisional value, we proceeded with the analysis of sequential ap-

Table 4
SN ratio and sensitivity for in-the-air versus underwater weights

	SN Ratio		Sensitivity	
Configuration	**Estimation**	**Confirmation**	**Estimation**	**Confirmation**
Optimal	8.83	8.63	−7.21	−6.87
Compared	2.17	4.48	−6.40	−6.57
Gain	6.66	4.15		

Table 5
SN ratio and sensitivity for transformability of shape

	SN Ratio		Sensitivity	
Configuration	**Estimation**	**Confirmation**	**Estimation**	**Confirmation**
Optimal	−1.58	−2.26	−0.32	−0.33
Compared	−7.66	−7.44	−0.84	−0.96
Gain	6.08	5.18		

proximation. A large value of sensitivity, *S*, indicates a small contraction rate. Figure 5 shows the response graph of appearance (the smaller-the-better characteristic).

Considering all results obtained so far, we concluded that the tendencies of the data related both to weighing and to transformability are almost consistent. Additionally, for separability, because the contraction rate becomes smaller as the filling density gets smaller in terms of the sensitivity, *S*, we can say that there is some consistency.

3. Optimal Configuration and Confirmatory Experiment

Based on the aforementioned results, we determined the combination of optimal conditions by first prioritizing the in-the-air versus underwater weights, and next, by referring to the transformability of shape and appearance (Table 3).

Tables 4 and 5 summarize SN ratios and sensitivities, at both the optimal and compared configurations. Now we computed the estimations using four factors, *A*, *B*, *C*, and *E*. Since the estimations and confirmatory results are fairly consistent, we can conclude that there is good reproducibility.

This experiment enabled us to mix a smaller amount of virgin materials (clay 1 and clay 2) and a larger amount of waste. Considering that the cost of industrial waste treatment is soaring and we are scheduled to use approximately 2800 tons of such tile materials on a yearly basis, we are expecting to contribute more to the disposal of industrial wastes and to the preservation of our environment and the Earth.

Reference

Toshichika Hirano, Kenichi Mizuno, Kouji Sekiguchi, and Takayoshi Matsunaga, 2000. Make tile of industry rejection by quality engineering. *Quality Engineering,* Vol. 8, No. 1, pp. 31–37.

This case study is contributed by Toshichika Hirano and Takayoshi Matsunaga.