Chapter V

Results and Discussion

The results of sand test in the Table 5-1 were indicated by four-number condition in order to show the levels of the factor A(grain finess number), B(clay content), C(starch content) and D(moisture content) respectively. For example, code 2112 means grain finess number of about 46, clay content of about 4.5 %, starch content of about 0.5 % and moisture of about 4 %.

Table 5-1. Summary of sand test results.

	Permeability			AVR	Comp. str. (100g/cm²)			AVR	% Loss on Ignition			AVR
1111	85	82	80	**82.33**	6.1	6.1	6	**6.07**	1.3	1.6	1.4	**1.43**
1112	65	68	72	**68.33**	6.6	5.9	6.7	**6.40**	3	3	3.2	**3.07**
1121	86	77	75	**79.33**	7.1	6.9	6.7	**6.90**	1.7	1.6	1.75	**1.68**
1122	62	62	63	**62.33**	6.3	6.4	6.1	**6.27**	3	3.1	3.25	**3.12**
1211	80	81	85	**82.00**	12	13	12.2	**12.40**	2.7	2.4	2.6	**2.57**
1212	65	69	70	**68.00**	6.9	7	6.9	**6.93**	3.7	4.1	3.5	**3.77**
1221	81	77	76	**78.00**	7.6	7.1	8.1	**7.60**	5	4.9	4.6	**4.83**
1222	55	52	54	**53.67**	8.4	8.9	8.2	**8.50**	4.3	4.6	4.1	**4.33**
2111	128	129	119	**125.33**	5.7	5.6	6.1	**5.80**	2.7	2.6	2.6	**2.63**
2112	85	84	81	**83.33**	6.6	5.8	6.4	**6.27**	4.4	4.1	4	**4.17**
2121	130	119	125	**124.67**	7.1	7.3	7.4	**7.27**	3.6	3.9	3.2	**3.57**
2122	73	77	74	**74.67**	6.3	6.3	6.5	**6.37**	6	5.9	5.75	**5.88**
2211	125	119	121	**121.67**	10.8	10.9	10.9	**10.87**	2.8	2.7	2.8	**2.77**
2212	78	73	73	**74.67**	7.7	7.9	8.1	**7.90**	3.6	3.4	3.65	**3.55**
2221	119	110	106	**111.67**	9.6	9.4	9.9	**9.63**	2.8	3.1	2.85	**2.92**
2222	60	65	62	**62.33**	8	8.6	8.1	**8.23**	4.4	4.5	4.1	**4.33**

Table 5-1 shows three properties of sand, which were varied by four-number conditions. All of the tests were done three times for each condition, and the average values were calculated. In this experimentation, the %loss on ignition was tested by burning 25 g of sampling sand.

The foundry process was investigated by adding factor E(pouring temperature) in which the pouring temperature was controlled as low(1550 °C) and high temperature(1620 °C). Casting were made and tested by stereological method. The results of this step indicate the effect of sand factors on the cavities occurrence, which is the aim of this work. Table 5-2 shows the result from stereological technique. Figure 5-1 shows pictures of castings and their sections.

Table 5-2. Summary of stereological measurement results.

	A	B	C	D	E	5 VALUES (% OF AREA)					TOTAL	AVR
1	1	1	1	1	1	12	13	13	4	0	**42**	**8.4**
2	1	1	1	1	2	0	0	0	0	0	**0**	**0**
3	1	1	1	2	1	6	4	0	0	0	**10**	**2**
4	1	1	1	2	2	0	0	0	0	0	**0**	**0**
5	1	1	2	1	1	10	3	0	0	0	**13**	**2.6**
6	1	1	2	1	2	0	0	0	0	0	**0**	**0**
7	1	1	2	2	1	10	12	0	0	0	**22**	**4.4**
8	1	1	2	2	2	0	0	0	0	0	**0**	**0**
9	1	2	1	1	1	0	0	0	0	0	**0**	**0**
10	1	2	1	1	2	0	0	0	0	0	**0**	**0**
11	1	2	1	2	1	10	11	6	6	0	**33**	**6.6**
12	1	2	1	2	2	4	0	0	0	0	**4**	**0.8**
13	1	2	2	1	1	13	22	24	16	14	**89**	**17.8**
14	1	2	2	1	2	10	4	0	0	0	**14**	**2.8**
15	1	2	2	2	1	38	40	35	30	25	**168**	**33.6**
16	1	2	2	2	2	10	11	9	0	0	**30**	**6**

Table 5-2. Summary of stereological measurement results (continued)

	A	B	C	D	E	S VALUES (% OF AREA)					TOTAL	AVR
17	2	1	1	1	1	0	0	0	0	0	0	0
18	2	1	1	1	2	0	0	0	0	0	0	0
19	2	1	1	2	1	10	9	0	0	0	19	3.8
20	2	1	1	2	2	0	0	0	0	0	0	0
21	2	1	2	1	1	5	0	0	0	0	5	1
22	2	1	2	1	2	0	0	0	0	0	0	0
23	2	1	2	2	1	12	10	0	0	0	22	4.4
24	2	1	2	2	2	0	0	0	0	0	0	0
25	2	2	1	1	1	0	0	0	0	0	0	0
26	2	2	1	1	2	0	0	0	0	0	0	0
27	2	2	1	2	1	0	0	0	0	0	0	0
28	2	2	1	2	2	0	0	0	0	0	0	0
29	2	2	2	1	1	6	11	0	0	0	17	3.4
30	2	2	2	1	2	5	0	0	0	0	5	1
31	2	2	2	2	1	17	10	12	9	0	48	9.6
32	2	2	2	2	2	4	3	0	0	0	7	1.4

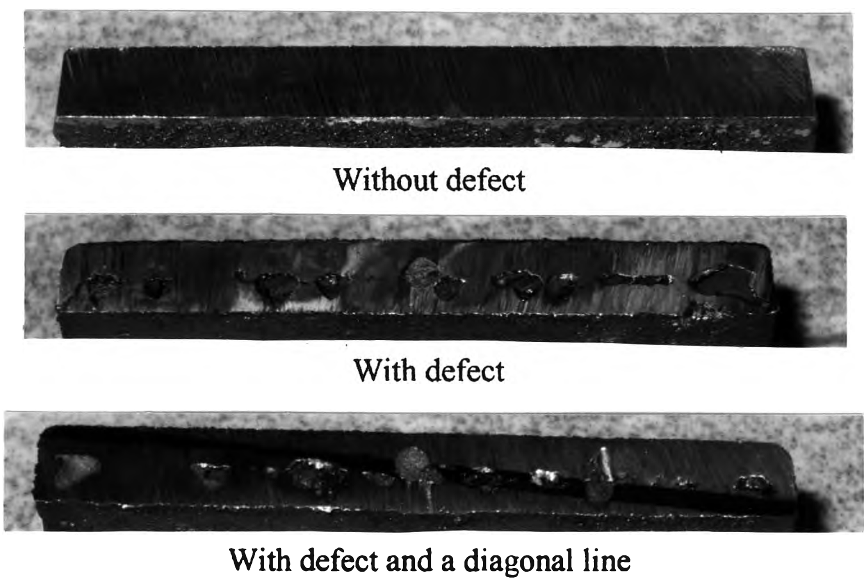

Figure 5-1. Cut surfaces of stereological measurement.

The grain distribution of sand has strong influences on sand properties, the various grain sizes of sand cause low permeability. The results of sieve analysis of sand are shown in Table 5-3, according to the distribution diagram of sand which is used as facing sand in the experiment (grain finess number of 46 and 49).

Table 5-3. Sieve analysis results.

Sieve No.	Factor	Weigth(g)	Results
20	10	0.2	2.0
30	20	3.0	60.0
40	30	16.1	483.0
50	40	34.5	1380.0
70	50	32.1	1605.0
100	70	10.7	749.0
140	100	1.7	170.0
200	140	0.5	70.0
270	200	0.2	40.0
pan	300	0.0	0.0
Total		99.0	4559.0
Finess No.			46.1

Sieve No.	Factor	Weigth(g)	Results
20	10	0.1	1.0
30	20	2.2	44.0
40	30	14.9	447.0
50	40	29.2	1168.0
70	50	31.8	1590.0
100	70	15.8	1106.0
140	100	2.6	260.0
200	140	0.8	105.0
270	200	0.5	90.0
pan	300	0.0	0.0
Total		97.8	4811.0
Finess No.			49.2

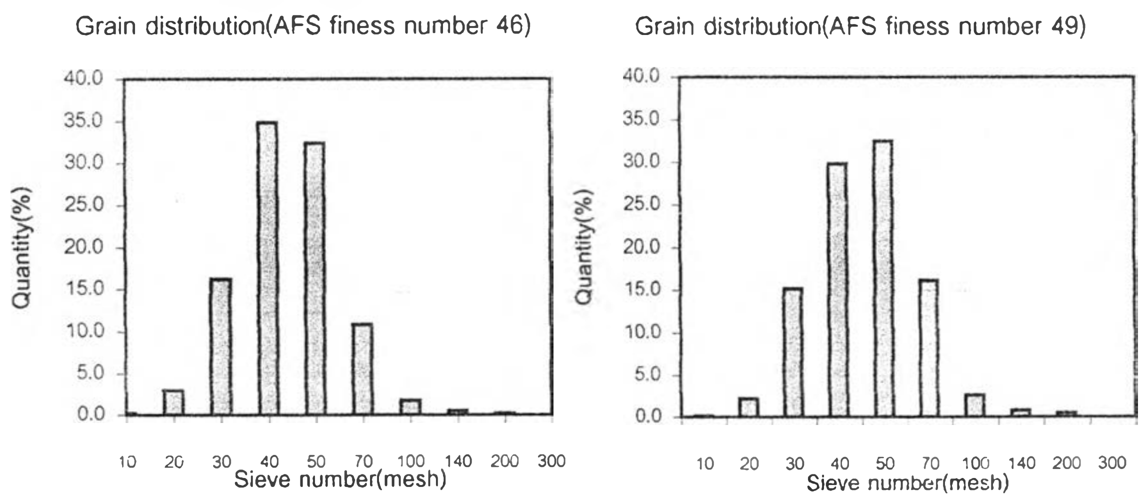

Figure 5-2. Distribution diagram of two grain finess numbers.

From sieve analysis, sand can be determined the AFS finess number. The AFS finess number cannot indicate the total of permeability, shape of grains needed to be checked. In the theory, rounded grain has higher permeability than the other shapes, i.e. subangular, angular and crystalline grain. The crystalline grain is not recommended for using in molding. Because the crystalline shape can be broken easily in milling, which causes low refractoriness, low permeability and need much binder. Shape of chromite sand in the experiment was investigated by optical microscope. Investigation by the optical microscope revealed that both coarse and fine grains are rounded grains. The drawing of rounded shape of chromite sand in the experiment is shown in Fig 5-3.

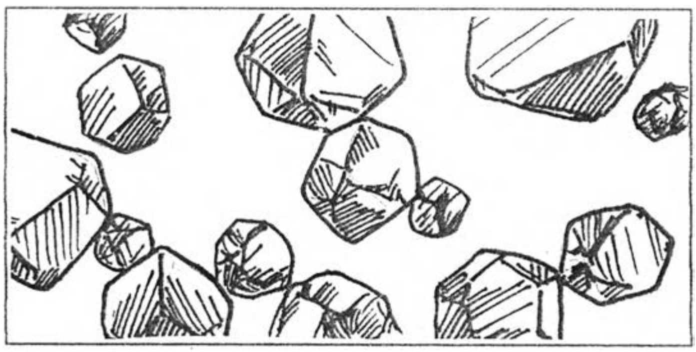

Figure 5-3. Rounded sand in the experiment.

The good permeability of molding sand is also determined by the summary weight (or percent by weight) of the three highest grain sizes from grain distribution, the total value should not less than 66.66 % by weight. In the bar chart of grain distribution, both finess number of 46 and finess number of 49 have the summary of the three highest bars are more than 66.66 %.

For the finess number of 46, the three highest grain size in the distribution diagram are shown as follows:

34.85%(Sieve No. 50) + 32.42%(Sieve No. 70) + 16.26%(Sieve No. 40)

= 83.53 % (more than 66 %)

For the finess number of 49, the most three highest amounts of grain size in the distribution diagram is shown as follows:

32.51%(Sieve No. 70) + 29.86%(Sieve No. 50) + 16.16%(Sieve No. 100)

= 78.53 % (more than 66 %)

Discussion of Sand Properties

The results of sand testing indicated the trends of sand properties which shown in Table 5-1. Some parts of data in Table 5-1 are shown in Table 5-4 to 5-11, which compares sand test result for "low" and "high" levels of each factor. The data from this comparing are plotted in Figure 5-4 to 5-11. The slopes of the lines explain whether the relation is a positive or negative.

Table 5-4. Effect of grain finess number on permeability (data from Table 5-1).

	Variation of grain finess number(factor A)			
	Code		Permeability	
	Low	High	Low	High
1	1 1 1 1	2 1 1 1	82.33	62.67
2	1 1 1 2	2 1 1 2	79.33	62.33
3	1 1 2 1	2 1 2 1	82	68
4	1 1 2 2	2 1 2 2	78	53.67
5	1 2 1 1	2 2 1 1	125.33	83.33
6	1 2 1 2	2 2 1 2	124.67	74.67
7	1 2 2 1	2 2 2 1	148.67	74.67
8	1 2 2 2	2 2 2 2	111.67	62.33

Table 5-5. Effect of clay content on permeability (data from Table 5-1).

	Variation of clay content(factor B)			
	Code		Permeability	
	Low	High	Low	High
1	1 1 1 1	1 2 1 1	82.33	82
2	1 1 1 2	1 2 1 2	68.33	68
3	1 1 2 1	1 2 2 1	79.33	78
4	1 1 2 2	1 2 2 2	62.33	53.67
5	2 1 1 1	2 2 1 1	125.33	121.67
6	2 1 1 2	2 2 1 2	83.33	74.67
7	2 1 2 1	2 2 2 1	124.67	111.67
8	2 1 2 2	2 2 2 2	74.67	62.33

Table 5-6. Effect of starch content on permeability (data from Table 5-1).

	Variation of starch content(factor C)			
	Code		Permeability	
	Low	High	Low	High
1	1 1 1 1	1 1 2 1	82.33	79.33
2	1 1 1 2	1 1 2 2	68.33	62.33
3	1 2 1 1	1 2 2 1	82	78
4	1 2 1 2	1 2 2 2	68	53.67
5	2 1 1 1	2 1 2 1	125.33	124.67
6	2 1 1 2	2 1 2 2	83.33	74.67
7	2 2 1 1	2 2 2 1	121.67	111.67
8	2 2 1 2	2 2 2 2	74.67	62.33

Table 5-7. Effect of moisture content on permeability (data from Table 5-1).

	Variation of moisture content(factor D)			
	Code		Permeability	
	Low	High	Low	High
1	1 1 1 1	2 1 1 1	82.33	62.67
2	1 1 1 2	2 1 1 2	79.33	62.33
3	1 1 2 1	2 1 2 1	82	68
4	1 1 2 2	2 1 2 2	78	53.67
5	1 2 1 1	2 2 1 1	125.33	83.33
6	1 2 1 2	2 2 1 2	124.67	74.67
7	1 2 2 1	2 2 2 1	148.67	74.67
8	1 2 2 2	2 2 2 2	111.67	62.33

Table 5-8. Effect of clay content on compressive strength (data from Table5-1).

	Variation of clay content(factor B)			
	Code		Compressive strength(g/cm^2)	
	Low	High	Low	High
1	1 1 1 1	1 2 1 1	607	1240
2	1 1 1 2	1 2 1 2	640	693
3	1 1 2 1	1 2 2 1	690	760
4	1 1 2 2	1 2 2 2	627	850
5	2 1 1 1	2 2 1 1	580	1087
6	2 1 1 2	2 2 1 2	627	790
7	2 1 2 1	2 2 2 1	727	963
8	2 1 2 2	2 2 2 2	637	823

Table 5-9. Effect of grain finess number on %loss on ignition (data from Table 5-1).

	Variation of grain finess number(factor A)			
	Code		%Loss on ignition	
	Low	High	Low	High
1	1 1 1 1	2 1 1 1	1.43	2.63
2	1 1 1 2	2 1 1 2	3.07	4.17
3	1 1 2 1	2 1 2 1	1.68	3.57
4	1 1 2 2	2 1 2 2	3.12	5.88
5	1 2 1 1	2 2 1 1	2.57	2.77
6	1 2 1 2	2 2 1 2	3.77	3.55
7	1 2 2 1	2 2 2 1	4.83	2.92
8	1 2 2 2	2 2 2 2	4.33	4.33

Table 5-10. Effect of starch content %loss on ignition (data from Table 5-1).

	Variation of starch content(factor C)			
	Code		%Loss on ignition	
	Low	High	Low	High
1	1 1 1 1	1 2 1 1	1.43	1.68
2	1 1 1 2	1 2 1 2	3.07	3.12
3	1 1 2 1	1 2 2 1	2.57	4.83
4	1 1 2 2	1 2 2 2	3.77	4.33
5	2 1 1 1	2 2 1 1	2.63	3.57
6	2 1 1 2	2 2 1 2	4.17	5.88
7	2 1 2 1	2 2 2 1	2.77	2.92
8	2 1 2 2	2 2 2 2	3.55	4.33

Table 5-11. Effect of moisture content on %loss on ignition (data from Table 5-1).

	Variation of moisture content(factor D)			
	Code		%Loss of ignition	
	Low	High	Low	High
1	1 1 1 1	1 1 1 2	1.43	3.07
2	1 1 2 1	1 1 2 2	1.68	3.12
3	1 2 1 1	1 2 1 2	2.57	3.77
4	1 2 2 1	1 2 2 2	4.83	4.33
5	2 1 1 1	2 1 1 2	2.63	4.17
6	2 1 2 1	2 1 2 2	3.57	5.88
7	2 2 1 1	2 2 1 2	2.77	3.55
8	2 2 2 1	2 2 2 2	2.92	4.33

The plotted data in Fig 5-4 to 5-11, the X-axis does not show continuing values. In each column in the diagrams, X-axis represents only two values; the black symbol is level 1 of X-axis and the white symbol is level 2 of X-axiz.. Actually, one diagram can show one line, but for the comparison, the eight columns in one diagram are plotted together, in order to compare each condition.

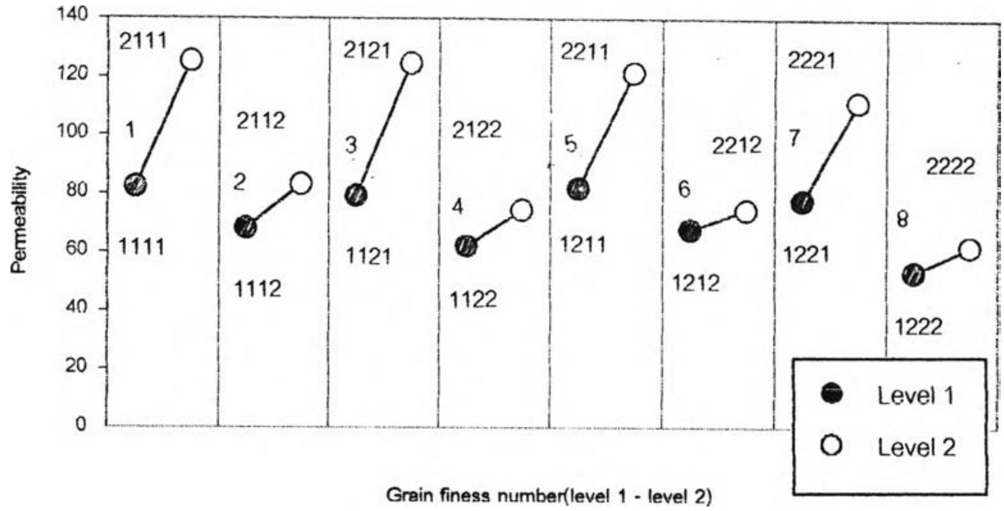

Figure 5-4. Effect of grain finess number on permeability of molding sand(Data from Table 5-4).

From Fig. 5-4, the rounded symbols are the level 2 of the values on X-axis. Each line in the diagram was plotted by two values of sand property which fixed three factors and varied one factors, which is plotted from low to high level. The line 1(1111, 2111) shows the maximum permeability because lowest additives were mixed in this formula. The comparison of other factors can be explained by group lines number 1(1111, 2111), 3(1121, 2121), 5(1211, 2211), 7(1221, 2221) which exhibited the permeability values higher than lines 2(1112, 2112), 4(1122, 2122), 6(1212, 2212), 8(1222, 2222) because of their lower moisture contents. The comparison between line 1(1111, 2111) and line 3(1121, 2121) or line 2(1112, 2112) and line 5(1211, 2211) with various starch contents, do not show much difference. Also in the comparison between line 1(1111, 2111) and line 5(1211, 2211) or line 3(1121, 2121) and line 7(1221, 2221) with various clay contents, and the comparison between line 1(1111, 2111) and line 7(1221, 2221) or line 2(1112,

2112) and line 8(1222, 2222) exhibit slight reduction of permeability, in spite of increasing clay and starch simultaneously.

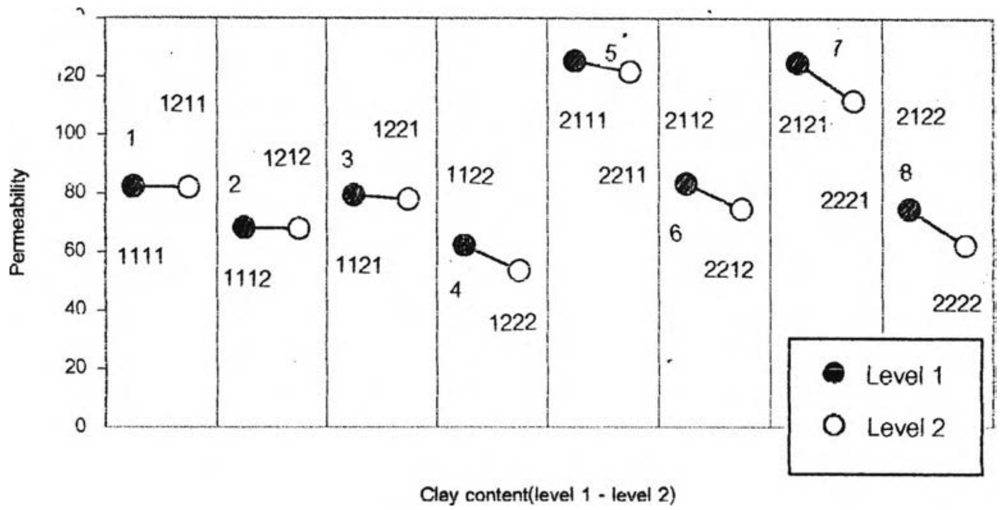

Figure 5-5. Effect of clay contents on permeability of molding sand (Data from Table 5-5).

From Fig 5-5, all of lines in the diagram show reducing of permeability with the little slopes. The comparison between line 1(1111, 1211) and 2(1112, 1212); line 3(1121, 1221) and 4(1122, 1222); line 5(2111, 2211) and 6(2112, 2212), and line 7(2121, 2221) and 8(2122, 2222) show the reduction of permeability because of the higher moisture contents.

The comparison of clay level from line 1(1111, 1211) and line 3(1121, 1221); line 2(1112, 1212) and line 4(1122, 1222); line 5(2111, 2211) and line 7 (2121, 2221); and line 6(2112, 2212) and line 8(2122, 2222) exhibit slight reduction of permeability.

The comparison of coarser grain size in line 1(1111, 1211) and line 5 (2111, 2211); line 2(1112, 1212) and line 7(2121, 2221); line 3(1121, 1221) and line 6(2112, 2212); and line 4(1122, 1222) and line 8(2122, 2222) show the increasing permeability. Because the coarse grain size will have greater porosity than finer grain size.

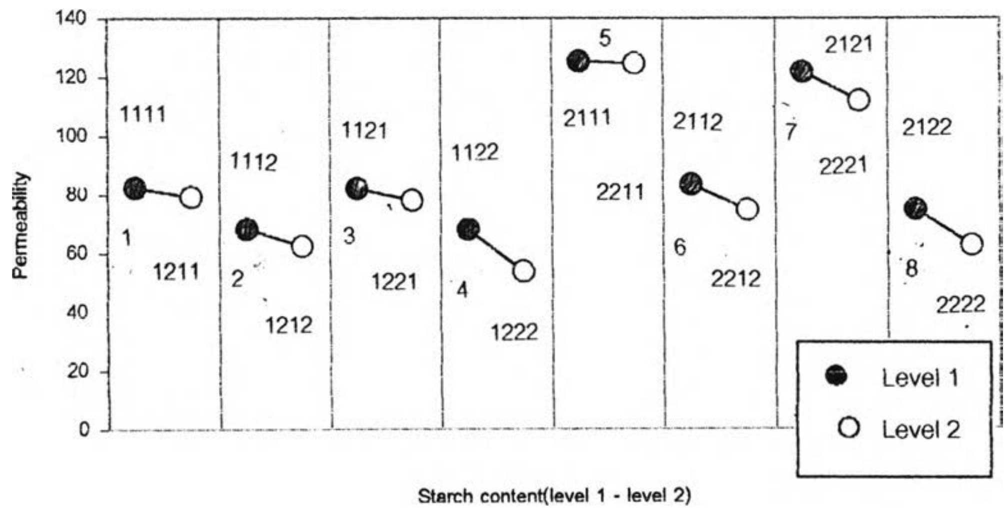

Figure 5-6. Effect of starch contents on permeability of molding sand (Data from Table 5-6).

From Fig 5-6, all lines in the diagram exhibit similar trend as shown in Fig 5-5, because clay and starch have the same influences on permeability.

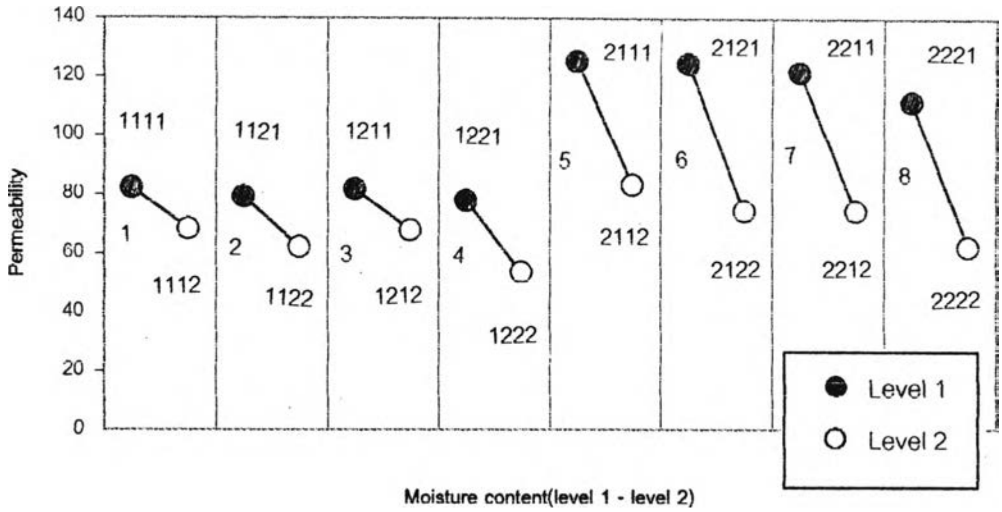

Figure 5-7. Effect of moisture contents on permeability of molding sand(Data from Table 5-7).

From Fig 5-7, the diagram shows very clear reduction of permeability when the moisture wa: increased.

The sand in group lines 5(2111, 2112), 6(2121, 2122), 7(2211, 2212) and 8(2221, 2222) have coarser grain than in the group lines 1(1111, 1112), 2(1121, 1122), 3(1211, 1212), and 4(1221, 1222). All lines in each group exhibit similar trend because the variation in each group are clay content and starch content. It is considered that clay content and starch content alone cannot reduce permeability to a significant level.

From figures 5-4 to 5-7, it can be concluded that permeability show the positive relation with grain finess number. Each line in the diagrams shows negative relation on moisture, clay and starch. The relation can be explained by the amount of water added with clay and starch. The spaces in sand were closed, especially, when clay absorbs water, and starch solute with water, which increase the viscosity of sand. This leads to the lower permeability of sand. Figure for grain finess number shows the positive relation, because the coarser the grains, the more the porosity of sand.

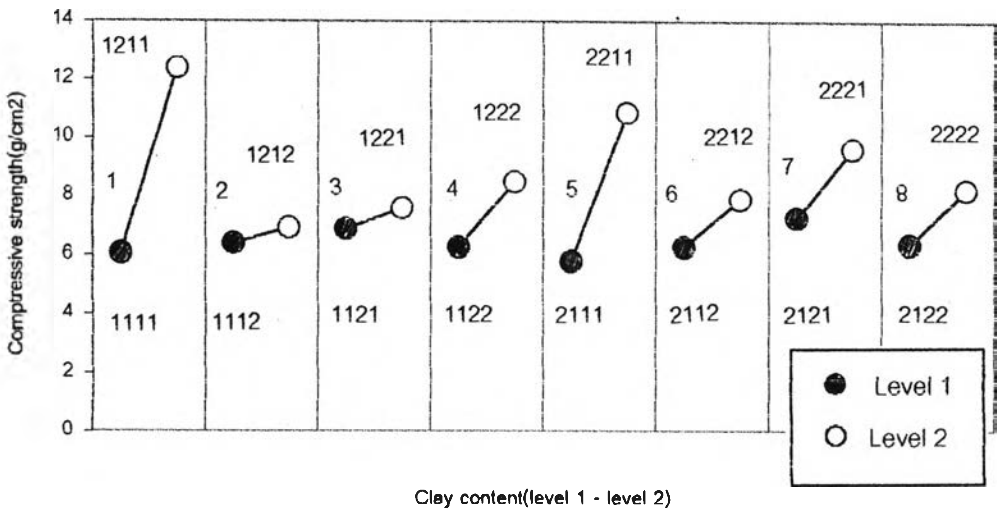

Figure 5-8. Effect of clay contents on compressive strength of molding sand. (Data from Table 5-8)

From Figure 5-8, compressive strength increased with the increased of clay content. Line 1(1111, 1211) and 5(2111, 2211) exhibited strong relationship because of low moisture and low starch contents. From this relation, it can be concluded that low level of water is enough for bonding sand. As starch absorbed water, it can be concluded that low moisture content and low starch content is the best condition for increasing the compressive strength by clay addition.

The comparison between line 1(1111, 1211) and 2(1112, 1212); line 3 (1121, 1221) and 4(1122, 1222); line 5(2111, 2211) and 6(2112, 2212) and line 7 (2121, 2221) and 8(2122, 2222) exhibit the lower compressive strength with higher moisture content. As same as the comparison between line 1(1111, 1211) and line

3(1121, 1221); line 2(1112, 1212) and line 4(1122, 1222); line 5(2111, 2211) and line 7(2121, 2221) and line 6(2112, 2212) and line 8(2122, 2222).

Clay was added to increase bonding. It is a main additive for improving compressive strength. Although starch was added to attain only good toughness for lifting off a pattern, but the toughness might have a relation with strength; thus starch may have affect on compressive strength. However, in this work, the effect of starch on compressive strength is not mentioned in literatures. Moreover, the raw data does not show a clear trend. Thus, this relation will not be concluded in this work.

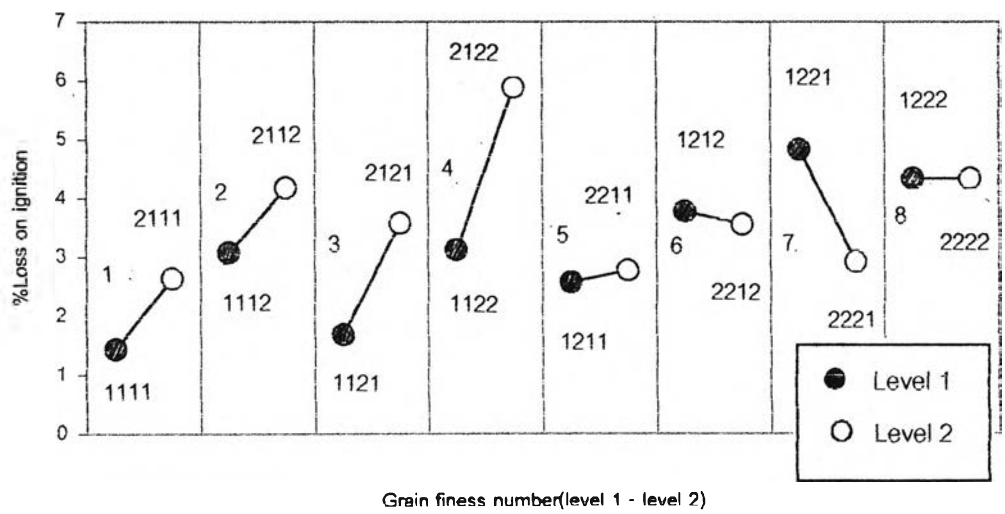

Figure 5-9. Effect of grain finess number on %loss on ignition of molding sand. (Data from Table 5-9)

The group lines 1(1111, 2111), 2(1112, 2112), 3(1121, 2121) and 4(1122, 2122) show the increasing of IG loss with the coarser grain. But in group line 5 (1211, 2211), 6(1212, 2212), 7(1221, 2221) and 8(1222, 2222), the IG loss tends to reduce with coarser grain. The difference of these two groups is clay content. The group lines 5, 6, 7, 8 have more clay content. With the increasing of clay content in coarse grain sand, grain can be bonded well than in fine grain sand. Increasing of the bonding lead to the lower vacancy, then decomposed gases cannot easily leak out of sand.

The comparison of the increasing of starch content in line 1(1111, 2111) and line 3(1121, 2121); line 2(1112, 2112) and line 4(1122, 2122); line 5(1211, 2211) and line 7(1221, 2221); and line 6(1212, 2212) and line 8(1222, 2222) show more IG loss. As same as the increasing of moisture content which are the comparison between line 1(1111, 2111) and line 2(1112, 2112); line 3(1121, 2121) and line 4(1122, 2122); line 5(1211, 2211) and line 6(1212, 2212); and line 7 (1221, 2221) and line 8(1222, 2222) because water and starch can be decomposed by pouring temperature.

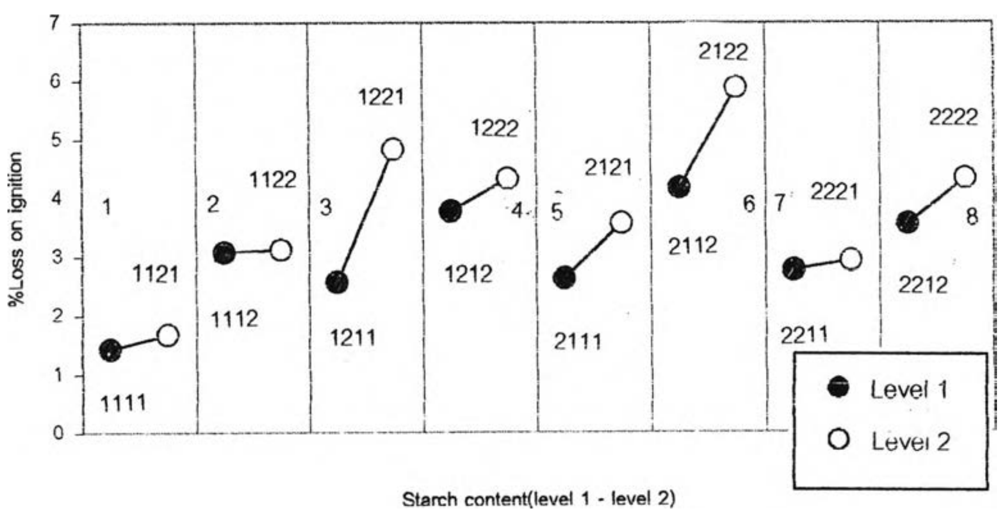

Figure 5-10. Effect of starch content on %loss on ignition of molding sand. (Data from Table 5-10)

From Fig 5-10, the more the starch content, the more the IG loss. The comparison between line 1(1111, 1121) and line 5(2111, 2121); line 2(1112, 1122) and 6(2112, 2122); line 3(1212, 1222) and line 7(2211, 2221); and line 4(1212, 1222) and line 8(2212, 2222) show higher IG loss with coarser grain coarser. Because the coarser grain resulted in higher permeability, thus, gases can easily leak out.

The comparison between line 1(1111, 1121) and line 2(1112, 1122); line 3 (1211, 1221) and line 4(1212, 1222); line 5(2111, 2121) and line 6(2112, 2122); and line 7(2211, 2221) and line 8(2212, 2222) show more IG loss with higher moisture content because of the decomposed gases from water.

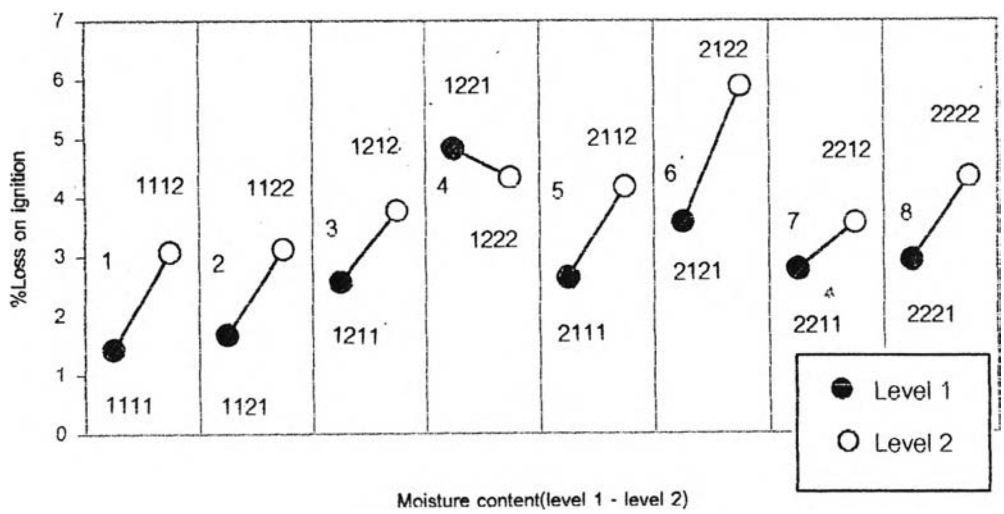

Figure 5-11. Effect of moisture contents on %loss on ignition of molding sand. (Data from Table 5-11)

From Fig 5-11, almost all of the lines show the increasing of IG loss with higher moisture content. The group lines 5(2111, 2112), 6(2121, 2122), 7(2211, 2212) and 8(2221, 2222) is for coarse grain, which have IG loss more than the group lines 1(1111, 1112), 2(1121, 1122), 3(1211, 1212) and 4(1221, 1222) which is for fine grain. The effect of clay on the loss on ignition in Fig 5-10 and Fig 5-11 can be explained in the similar manner as the Fig 5-9.

From figure 5-9 to 5-11, it can be concluded that, the % loss on ignition is a property which indicates increasing of gases and depends on the amount of decomposable additives in sand. Moisture and starch are two additives that can be easily decomposed in fire. Thus, they show a positive relation with %loss on ignition. The grain finess number also exhibit the affects on %loss on ignition, since coarser grain have better permeability; thus a good permeability resulted in good ventilation of gasses, especially gasses from loss on ignition.

Permeability and %loss on ignition were tested to investigate the blowhole and pinhole problem. The data is shown in Table 5-12 as well as Figure 5-12 and 5-13. Figure 5-12 and 5-13 are graphs showing the correlation of sand properties with pinhole measurement and pouring temperature.

Table 5-12. Relation between sand properties and presence of blowhole as determined by stereological method (data from Table 5-1 and 5-2).

Permeability (Average)	% Loss on ignition (Average)	Blowhole masurement result (fractions on diagonal line)									
		Low pouring temperature					High pouring temperature				
82	1.3	0.1	0.1	0.1	0	0	0	0	0	0	0
68	3	0.1	0	0	0	0	0	0	0	0	0
79	1.7	0.1	0	0	0	0	0	0	0	0	0
62	3	0.1	0.1	0	0	0	0	0	0	0	0
82	2.7	0	0	0	0	0	0	0	0	0	0
68	3.7	0.1	0.1	0.1	0.1	0	0	0	0	0	0
78	5	0.1	0.2	0.2	0.2	0.1	0.1	0	0	0	0
54	4.3	0.4	0.4	0.4	0.3	0.3	0.1	0.1	9	0	0
125	2.7	0	0	0	0	0	0	0	0	0	0
83	4.4	0.1	0.1	0	0	0	0	0	0	0	0
125	3.6	0.1	0	0	0	0	0	0	0	0	0
75	6	0.1	0.1	0	0	0	0	0	0	0	0
122	2.8	0	0	0	0	0	0	0	0	0	0
75	3.6	0	0	0	0	0	0	0	0	0	0
112	2.8	0.1	0.1	0	0	0	0.1	0	0	0	0
62	4.4	0.2	0.1	0.1	0.9	0	0	0	0	0	0

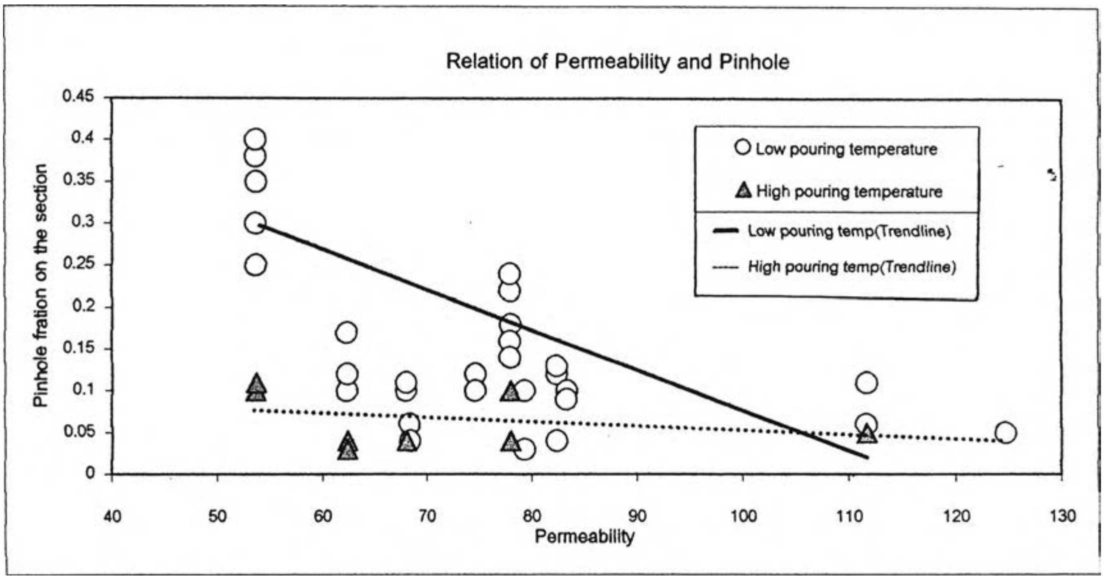

Figure 5-12. Correlation between permeability, blowhole and pouring temperature. (Data from Table 5-1 and 5-2)

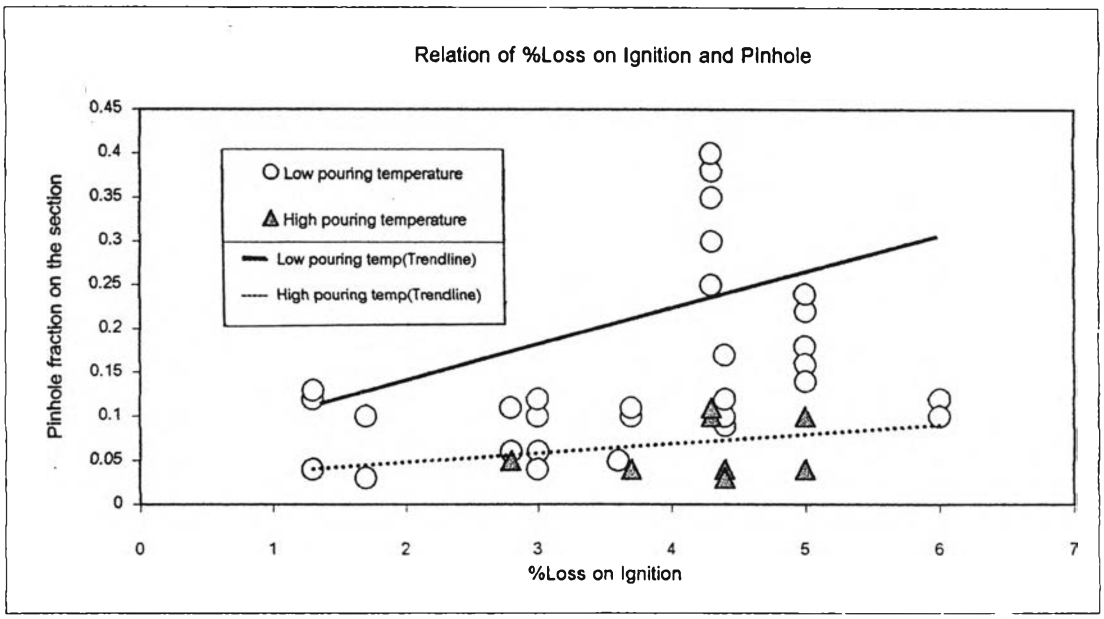

Figure 5-13. Correlation between % loss on ignition, blowhole and pouring temperature. (Data from Table 5-1 and 5-2)

By using the least square method, all of trendlines in the diagrams can show the linear equations as follows:

Equation of linear relation : $Y = a_o + a_1 X$

From the least square method, equations for indication a_o and a_1 are :

$$a_o = \frac{\left(\sum_{i=1}^{n} Y_i\right)\left(\sum_{i=1}^{n} X_i^2\right) - \left(\sum_{i=1}^{n} X_i Y_i\right)\left(\sum_{i=1}^{n} X_i\right)}{n\left(\sum_{i=1}^{n} X_i^2\right) - \left(\sum_{i=1}^{n} X_i\right)^2}$$

$$a_1 = \frac{n\left(\sum_{i=1}^{n} X_i Y_i\right) - \left(\sum_{i=1}^{n} X_i\right)\left(\sum_{i=1}^{n} Y_i\right)}{n\left(\sum_{i=1}^{n} X_i^2\right) - \left(\sum_{i=1}^{n} X_i\right)^2}$$

From the diagram of permeability (Figure 5-12.)

The Y axis is values of blowhole fraction on the section.

The X axis is values of permeability.

At low pouring temperature condition, the equation is:

$$Y = 0.541979 - 0.00469\ X$$

At high pouring temperature condition, the equation is:

$$Y = 0.10979 - 0.00062\ X$$

From diagram of %loss on ignition (Figure 5-13.)

The Y axis is values of blowhole fraction on the section.

The X axis is values of %loss on ignition.

At low pouring temperature condition, the equation is:

$$Y = 0.060415 + 0.036336\ X$$

At high pouring temperature condition, the equation is:

$$Y = 0.020062 + 0.01098\ X$$

Figure 5-12 shows the effect of permeability on pinhole. This figure indicated that pinhole can be reduced by increasing the permeability. In contrast with Figure 5-13, the higher % loss on ignition will lead to more pinholes. Both of the Figures clearly explained the trend of the low pouring temperature conditions. The pinhole and blowhole can occur in the low pouring temperature process more than in high pouring temperature. Although the plot shows fewer blowholes occur in the high pouring temperature condition, the trend of high pouring temperature might as same as the low pouring temperature condition. The high pouring temperature is a condition, which is done for avoiding pinhole. Although high temperature cause more gas from sand, but its longer solidification time can facilitate the molten metal to have enough time for degassing.

Statistical Analysis

This analysis compare the significance of each factor, i.e., grain finess number (grain size), clay content, starch content, moisture content and pouring temperature on the test result. From Table 5-1 and 5-2, statistical analysis was employed to signify results, which are shown as follows:

Analysis of Permeability Test Result

Table 5-13. Effect of grain size, clay, starch and moisture on permeability

A	B	C	D	Permeability data			AVR	Total	Square of data		
1	1	1	1	85	82	80	82.33	247	7225	6724	6400
1	1	1	2	65	68	72	68.33	205	4225	4624	5184
1	1	2	1	68	77	75	79.33	220	4624	5929	5625
1	1	2	2	62	62	63	62.33	187	3844	3844	3969
1	2	1	1	80	81	85	82	246	6400	6561	7225
1	2	1	2	65	69	70	68	204	4225	4761	4900
1	2	2	1	81	77	76	78	234	6561	5929	5776
1	2	2	2	55	52	54	53.67	161	3025	2704	2916
2	1	1	1	128	129	119	125.33	376	16384	16641	14161
2	1	1	2	85	84	81	83.33	248	7225	7056	6561
2	1	2	1	130	119	125	124.67	374	16900	14161	15625
2	1	2	2	73	77	74	74.67	224	5329	5929	5476
2	2	1	1	125	119	121	121.67	365	15625	14161	14641
2	2	1	2	78	73	73	74.67	224	6084	5329	5329
2	2	2	1	119	110	106	111.67	335	14161	12100	11236
2	2	2	2	60	65	62	62.33	1878	3600	4225	3844

From Table 5-13, preliminary data and calculation are shown as follows:

Factor	A	B	C	D
Total(Level 1)	1704	2081	2115	2397
Total(Level 2)	2333	1956	1922	1640
Effect(L2-L1)	629	-125	-193	-757

a) $\Sigma A_1 = 1704$, $\Sigma A_2 = 2333$

$\therefore$ Sum of Squares A $= SS_A = (\Sigma A_1 - \Sigma A_2)^2$/Total number of castings

$= (1704 - 2333)^2/48$

$= 8242.52$

b) $\Sigma B_1 = 2081$, $\Sigma B_2 = 1956$

$\therefore$ Sum of Squares B $= SS_B = (\Sigma B_1 - \Sigma B_2)^2/48$

$= (2081 - 1956)^2/48$

$= 325.52$

c) $\Sigma C_1 = 2115$, $\Sigma C_2 = 1922$

$\therefore$ Sum of Squares C $= SS_C = (\Sigma C_1 - \Sigma C_2)^2/48$

$= (2115 - 1922)^2/48$

$= 776.02$

d) $\Sigma D_1 = 2397$, $\Sigma D_2 = 1640$

$\therefore$ Sum of Squares D $= SSD = (\Sigma D_1 - \Sigma D_2)^2/48$

$= (2397 - 1640)^2/48$

$= 11938.52$

f)SS_{Total} = $(X_1^2 + X_2^2 + X_3^2 + \ldots X_{160}^2) - ((1704+2333)^2/48)$

$= 364983 - (4037^2/48)$

$= 25454.48$

Residual = $25454.48 - (SS_A + SS_B + SS_C + SS_D + SS_E)$

$= 25454.48 - 21282.58$

$= 4171.9$

Source	Sum of squares	f(n – 1)*	Variance	Variance of Ratio
A	8242.52	2	4121.26	38.53
B	325.52	2	162.76	1.52
C	776.02	2	388.01	3.63
D	11938.52	2	5969.26	55.80
Residual	4171.9	39	106.97	1

* For A, B, C, D, E f = n – 1 , 3 – 1 = 2

* For residual (48 – 1) – (2 + 2 + 2 + 2) = 39

For F-distribution of 2/39

		2/24	2/39	2/60
90%	10	2.54	2.42	2.39
95%	5	3.40	3.18	3.15
99%	1	5.61	5.02	4.98

Compare F-distribution values with variance of ratio for indicate significant level of each factor.

	Variance of Ratio	Significance level
A) Finess number	38.53	> 99% (the most significant)
B) Clay	1.52	< 90%
C) Starch	3.63	> 95%
D) Water	55.81	> 99% (the most significant)

Analysis of Compressive Strength Test Result

Table 5-14. Effect of grain size, clay, starch and moisture on compressive strength

A	B	C	D	Compressive Str. data			AVR	Total	Square of data		
1	1	1	1	6.1	6.1	6	6.1	18.2	37.21	37.21	36
1	1	1	2	6.6	5.9	6.7	6.4	19.2	43.56	34.81	44.89
1	1	2	1	7.1	6.9	6.7	6.9	20.7	50.41	47.61	44.89
1	1	2	2	6.3	6.4	6.1	6.3	18.8	39.69	40.96	37.21
1	2	1	1	12	13	12.2	12.4	37.2	144	169	148.84
1	2	1	2	6.9	7	6.9	6.9	20.8	47.61	49	47.61
1	2	2	1	7.6	7.1	8.1	7.6	22.8	57.76	50.41	65.61
1	2	2	2	8.4	8.9	8.2	8.5	25.5	70.56	79.21	67.24
2	1	1	1	5.7	5.6	6.1	5.8	17.4	32.49	31.36	37.21
2	1	1	2	6.6	5.8	6.4	6.3	18.8	43.56	33.64	40.96
2	1	2	1	7.1	7.3	7.4	7.3	21.8	50.41	53.29	54.76
2	1	2	2	6.3	6.3	6.5	6.4	19.1	39.69	39.69	42.25
2	2	1	1	10.8	10.9	10.9	10.9	32.6	116.64	118.81	118.81
2	2	1	2	7.7	7.9	8.1	7.9	23.7	59.29	62.41	65.61
2	2	2	1	9.6	9.4	9.9	9.6	28.9	92.16	88.36	98.01
2	2	2	2	8	8.6	8.1	8.2	24.7	64	73.96	65.61

From Table 5-14, preliminary data and calculation are shown as follows:

Factor	A	B	C	D
Total(Level 1)	183.2	154	187.9	199.6
Total(Level 2)	187	216.2	182.3	170.6
Effect(L2-L1)	3.8	62.2	-5.6	-29

a)$\Sigma A_1 = 183.2, \Sigma A_2 = 187$

∴Sum of Squares A $= SS_A = (\Sigma A_1 - \Sigma A_2)^2$/Total number of castings

$= (183.2 - 187)^2/48$

$= 0.3$

b)$\Sigma B_1 = 154, \ \Sigma B_2 = 216.2$

∴Sum of Squares B $= SS_B = (\Sigma B_1 - \Sigma B_2)^2/48$

$= (154 - 216.2)^2/48$

$= 80.6$

c)$\Sigma C_1 = 187.9, \ \Sigma C_2 = 182.3$

∴Sum of Squares C $= SS_C = (\Sigma C_1 - \Sigma C_2)^2/48$

$= (187.9 - 182.3)^2/48$

$= 0.65$

d)$\Sigma D_1 = 199.6, \ \Sigma D_2 = 170.6$

∴Sum of Squares D $= SSD = (\Sigma D_1 - \Sigma D_2)^2/48$

$= (199.6 - 170.6)^2/48$

$= 17.52$

f)SS_{Total} = $(X_1^2 + X_2^2 + X_3^2 + \ldots X_{160}^2) - ((183.2+187)^2 /48)$

$= 3014.28 - (370.2^2 /48)$

$= 159.11$

Residual = $159.11 - (SS_A + SS_B + SS_C + SS_D + SS_E)$

$= 159.11 - 99.07$

$= 60.04$

Source	Sum of squares	f(n – 1)*	Variance	Variance of Ratio
A	0.3	2	0.15	0.1
B	80.6	2	40.3	26.17
C	0.65	2	0.33	0.21
D	17.52	2	8.76	5.69
Residual	60.04	39	1.54	1

* As same as permeability analysis

For F-distribution of 2/39 (as same as permeability analysis)

The significance level are shown as follow:

	Variance of Ratio	Significance level
A) Finess number	0.1	< 90%
B) Clay	26.17	> 99% (the most significant)
C) Starch	0.21	< 90%
D) Water	5.69	> 99% (the most significant)

Analysis of %Loss on Ignition Test Result

Table 5-15. Effect of grain size, clay, starch and moisture on %loss on ignition test

A	B	C	D	%Loss on Ignition			AVR	Total	Square of %Loss on Ignition		
1	1	1	1	1.3	1.6	1.4	1.43	4.30	1.69	2.56	1.96
1	1	1	2	3	3	3.2	3.07	9.20	9.00	9.00	10.24
1	1	2	1	1.7	1.6	1.75	1.68	5.05	2.89	2.56	3.06
1	1	2	2	3	3.1	3.25	3.12	9.35	9.00	9.61	10.56
1	2	1	1	2.7	2.4	2.6	2.57	7.70	7.29	5.76	6.76
1	2	1	2	3.7	4.1	3.5	3.77	11.30	13.69	16.81	12.25
1	2	2	1	5	4.9	4.6	4.83	14.50	25.00	24.01	21.16
1	2	2	2	4.3	4.6	4.1	4.33	13.00	18.49	21.16	16.81
2	1	1	1	2.7	2.6	2.6	2.63	7.90	7.29	6.76	6.76
2	1	1	2	4.4	4.1	4	4.17	12.50	19.36	16.81	16.00
2	1	2	1	3.6	3.9	3.2	3.57	10.70	12.96	15.21	10.24
2	1	2	2	6	5.9	5.75	5.88	17.65	36.00	34.81	33.06
2	2	1	1	2.8	2.7	2.8	2.77	8.30	7.84	7.29	7.84
2	2	1	2	3.6	3.4	3.65	3.55	10.65	12.96	11.56	13.32
2	2	2	1	2.8	3.1	2.85	2.92	8.75	7.84	9.61	8.12
2	2	2	2	4.4	4.5	4.1	4.33	13.00	19.36	20.25	16.81

From Table 5-15, preliminary data and calculation are shown as follows:

Factor	A	B	C	D
Total(Level 1)	74.4	76.65	71.85	67.2
Total(Level 2)	89.45	87.2	92	96.65
Effect(L2-L1)	15.05	10.55	20.15	29.45

a)$\sum A_1$ = 74.4, $\sum A_2$ = 89.45

$\therefore$Sum of Squares A = $SS_A = (\sum A_1 - \sum A_2)^2$/Total number of castings

$= (74.4 - 89.45)^2/48$

$= 4.72$

b)$\sum B_1$ = 76.65, $\sum B_2$ = 87.2

$\therefore$Sum of Squares B = $SS_B = (\sum B_1 - \sum B_2)^2/48$

$= (76.65 - 87.2)^2/48$

$= 2.32$

c)$\sum C_1$ = 71.85, $\sum C_2$ = 92

$\therefore$Sum of Squares C = $SS_C = (\sum C_1 - \sum C_2)^2/48$

$= (71.85 - 92)^2/48$

$= 8.46$

d)$\sum D_1$ = 67.2, $\sum D_2$ = 96.65

$\therefore$Sum of Squares D = $SSD = (\sum D_1 - \sum D_2)^2/48$

$= (67.2 - 96.65)^2/48$

$= 18.07$

f)$SS_{Total} = (X_1^2 + X_2^2 + X_3^2 + \ldots X_{160}^2) - ((74.4+89.45)^2/48)$

$= 612.77 - (163.85^2/48)$

$= 53.46$

Residual = $53.46 - (SS_A + SS_B + SS_C + SS_D + SS_E)$

$= 53.46 - 33.57$

$= 19.89$

Source	Sum of squares	f(n – 1)*	Variance	Variance of Ratio
A	4.72	2	2.36	4.62
B	2.32	2	1.16	2.27
C	8.46	2	4.23	8.29
D	18.07	2	9.04	17.73
Residual	19.89	39	0.51	1

*As same as permeability analysis

For F-distribution of 2/39 (as same as permeability analysis)

	Variance of Ratio	Significance level
A) Finess number	4.62	> 95%
B) Clay	2.27	> 90%
C) Starch	8.29	> 99% (the most significant)
D) Water	17.73	> 99% (the most significant)

Analysis of blowhole and pinhole occurrence

Table 5-16. Data from Table 5-2 for statistical analysis of blowhole occurrence.

	A	B	C	D	E	5 VALUES (% OF AREA)					TOTAL	AVR	Square of %of Area				
1	1	1	1	1	1	12	13	13	4	0	42	8.4	144	169	169	16	0
2	1	1	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0
3	1	1	1	2	1	6	4	0	0	0	10	2	36	16	0	0	0
4	1	1	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0
5	1	1	2	1	1	10	3	0	0	0	13	2.6	100	9	0	0	0
6	1	1	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0
7	1	1	2	2	1	10	12	0	0	0	22	4.4	100	144	0	0	0
8	1	1	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0
9	1	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
10	1	2	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0
11	1	2	1	2	1	10	11	6	6	0	33	6.6	100	121	36	36	0
12	1	2	1	2	2	4	0	0	0	0	4	0.8	16	0	0	0	0
13	1	2	2	1	1	13	22	24	16	14	89	17.8	169	484	576	256	196
14	1	2	2	1	2	10	4	0	0	0	14	2.8	100	16	0	0	0
15	1	2	2	2	1	38	40	35	30	25	168	33.6	1444	1600	1225	900	625
16	1	2	2	2	2	10	11	9	0	0	30	6	100	121	81	0	0
17	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
18	2	1	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0
19	2	1	1	2	1	10	9	0	0	0	19	3.8	100	81	0	0	0
20	2	1	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0
21	2	1	2	1	1	5	0	0	0	0	5	1	25	0	0	0	0
22	2	1	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0
23	2	1	2	2	1	12	10	0	0	0	22	4.4	144	100	0	0	0
24	2	1	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0
25	2	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
26	2	2	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0
27	2	2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0
28	2	2	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0
29	2	2	2	1	1	6	11	0	0	0	17	3.4	36	121	0	0	0
30	2	2	2	1	2	5	0	0	0	0	5	1	25	0	0	0	0
31	2	2	2	2	1	17	10	12	9	0	48	9.6	289	100	144	81	0
32	2	2	2	2	2	4	3	0	0	0	7	1.4	16	9	0	0	0

From Table 5-16, preliminary data and calculation are shown as follows:

Factor	A	B	C	D	E
Total(level 1)	425	133	108	185	488
Total(level 2)	123	415	440	363	60
Effect(L1-L2)	-302	288	332	178	-428

a) $\Sigma A_1 = 425$, $\Sigma A_2 = 123$

$\therefore$ Sum of Squares A $= SS_A = (\Sigma A_1 - \Sigma A_2)^2$/Total number of castings

$= (425 - 123)^2/160$

$= 570.025$

b) $\Sigma B_1 = 133$, $\Sigma B_2 = 415$

$\therefore$ Sum of Squares B $= SS_B = (\Sigma B_1 - \Sigma B_2)^2/160$

$= (133 - 415)^2/160$

$= 497.025$

c) $\Sigma C_1 = 108$, $\Sigma C_2 = 440$

$\therefore$ Sum of Squares C $= SS_C = (\Sigma C_1 - \Sigma C_2)^2/160$

$= (108 - 440)^2/160$

$= 688.9$

d) $\Sigma D_1 = 185$, $\Sigma D_2 = 363$

$\therefore$ Sum of Squares D $= SSD = (\Sigma D_1 - \Sigma D_2)^2/160$

$= (185 - 363)^2/160$

$= 198.025$

e) ΣE_1 = 488, ΣE_2 = 60

$\therefore$ Sum of Squares E $= SS_E = (\Sigma E_1 - \Sigma E_2)^2/160$

$= (488 - 60)^2/160$

$= 1144.9$

f) $SS_{Total} = (X_1^2 + X_2^2 + X_3^2 + \dots X_{160}^2) - (548^2/160)$

$= 10612 - 1876.9$

$= 8285.1$

Residual = $8285.1 - (SS_A + SS_B + SS_C + SS_D + SS_E)$

$= 8285.1 - 2950.2$

$= 5334.9$

Source	Sum of squares	f(n – 1)*	Variance	Variance of Ratio
A	570.025	4	142.5	3.71
B	497.025	4	124.3	3.24
C	688.9	4	172.2	4.49
D	198.025	4	49.51	1.29
E	1144.9	4	286.2	7.46
Residual	5334.9	139	38.38	1

* For A, B, C, D, E $f = n - 1$, $5 - 1 = 4$
* For residual $(160 - 1) - (4 + 4 + 4 + 4 + 4) = 139$

For F-distribution of 4/139

		4/60	4/139	4/α
90%	10	2.04	1.94	1.94
95%	5	2.53	2.37	2.37
99%	1	3.65	3.32	3.32

	Variance of ratio	Significance level
A) Finess number	3.71	> 99% (the most significant)
B) Clay	3.24	> 90%
C) Starch	4.49	> 99% (the most significant)
D) Moisture	1.29	< 90%
E) Pouring temp.	7.46	> 99% (the most significant)

The factor that has significance level higher than 99% is the most significance factor for that property.

In the analysis of blowhole and pinhole occurrence, effect of moisture on blowhole occurrence should have more than clay and starch. It is suspected that this result may be in error due to the experimentation. This is became the molds were made in the evening of day, pouring process started in the morning of the next day. Using this assumption, molding sand was tested by making a mold and test moisture after held it over a night. In the mold cavity, the surface of 1 to 2 mm thickness of facing sand loosed moisture around 0.5 to 1 %, which made the significance of moisture lower than it should be.

The high pouring temperature condition may have effects on shrinkage cavity. However, in the experimental results, there was no shrinkage cavity, because the casting was a thin plate which had a high cooling rate to avoid shrinkage.

The aim of this work is to conclude that which condition can minimize blowhole. From the analysis, the most significant factors of defect occurrence are grain finess number which controls permeability, starch content which is decomposed to be gas, and pouring temperature. The preliminary conclusion is that grain finess number, starch content and pouring temperature should be 46 (coarse grain), 0.5 %(low level) and of 1620 °C (high pouring temperature) accordingly in order to minimize blowhole.

Gases in molten metal are from decomposed water and starch in mixed sand. Moreover, moisture content is the most significant factor of permeability, compressive strength and loss on ignition. Thus, moisture content should be the most significant factor on defect occurrence (the error of moisture content can be explained by making mold over a night before pouring.). Moisture content level is needed to be at low level for controlling sand properties. The moisture content of 2.5 % is the condition that minimizes blowhole.

From Table 5-2, the zero defect appeared in 15 conditions, i.e. 11112, 11122, 11212, 11222, 12111, 12112, 21111, 21112, 21122, 21212, 21222, 22111, 22112, 22121 and 22122. The 15 conditions of zero defect are shown in Table 5-17.

Figure 5-17. The 15 zero defect conditions from Table 5-2.

	Grain finess number	Clay content	Starch content	Moisture content	Pouring Temperature
1	1	1	1	1	2
2	1	1	1	2	2
3	1	1	2	1	2
4	1	1	2	2	2
5	1	2	1	1	1
6	1	2	1	1	2
7	2	1	1	1	1
8	2	1	1	1	2
9	2	1	1	2	2
10	2	1	2	1	2
11	2	1	2	2	2
12	2	2	1	1	1
13	2	2	1	1	2
14	2	2	1	2	1
15	2	2	1	2	2
Total of level 1	**6**	**9**	**11**	**9**	**4**
Total of level 2	**9**	**6**	**4**	**6**	**11**

The signification of level 1 and 2 of each factor was shown in Table 4-1.

The zero defect conditions, which have the levels of grain finess number, starch content, moisture content and pouring temperature that are similar to the indicates of those indicates in the analysis, are 21112 and 21112. Since these two conditions have the same pouring temperature. The difference of these two conditions have the same by pouring temperature, the difference of these two conditions is the same formulas. The formulas of these two zero defect conditions are 2111 and 2211. The 2111 formula has sand properties of 125 permeability, 580 g/cm^2 compressive strength and 2.63 %loss on ignition. The 2211 formula has sand properties of 121 permeability, 1080 g/cm^2 compressive strength and 2.77 %loss on ignition. The values of permeability and %loss on ignition of these two zero defect conditions are almost equal, but the compressive strength is quiet different. The standard of green compressive strength in the factory is 500-600 g/cm^2; thus, low clay content can make the value of compressive strength to be enough for using in the factory. Too high compressive strength will cause difficulty in ramming off the mold. Thus, the best condition for minimize blowhole and pinhole is the condition 21112.

By using visual analysis in Table 5-17, the best condition can be selected by the total of level 1 and level 2. The level that shows higher number of each factor is the best level for the zero defect condition. The best level of grain finess number is level 2 with ratio between level 2 and level 1 of 9 : 6; the best level of clay content is level 1 with ratio between level 1 and level 2 of 9 : 6; the best level of starch content is level 1 with ratio between level 1 and level 2 of 11 : 4; the best level of moisture content is level 1 with ratio between level 1 and level 2 of 9 : 6 and the best level of pouring temperature is level 2 with ratio between level 2 and level 1 of 11 : 4. Thus, the best condition from the total values is 21112.

From the analysis, the best condition can be confirmed with theories. The discussion of advantages and disadvantages of condition 21112 are show in Table 5-18.

From the analysis, the best condition can be confirmed with theories. The discussion of advantages and disadvantages of condition 21112 are show in Table 5-18.

Table 5-18. Summary of the best condition for zero defect.

Conditions	Advantages	Disadvantages
Coarse grain size	-Good permeability	
Low clay content	-Good permeability -Easier ram off the mold(or shaking out)	-Low compressive strength
Low starch content	-Good permeability -Low gas in process	-Low toughness
Low moisture content	-Good permeability -Low gas in process	
High pouring temperature	-Longer time for solidification and gases leaking(reduce pinhole and blowhole)	-More expensive(energy) -More shrinkage -Greater chance of burn on -More dead clay -Shorter refractories lives

From Table 5-18, although the high pouring temperature has a lot of disadvantages, high pouring temperature helps casting in the process used in the case study that needs to pour a lot of molds by one ladle. However, the process which uses single ladle for many molds is risk for defect occurrence because the pouring temperature will drop in the later molds. Thus, the temperature drop is the most serious problem on this case. The chance of gas defect occurrence by mold sequence of pouring time can be explained by the theory of shorter solidification time with lower pouring temperature, which is shown in Fig 2-5.

On the other hand, the process which uses one ladle pours to a few molds is common in the factories. This kind of process allows low pouring temperature. Moreover, cost saving which is the most important factor in the factories also enhances using low pouring temperature. Therefore, the summary of the zero defect conditions which have low pouring temperature is shown in Table 5-19.

Table 5-19. The four zero defect conditions with low pouring temperature.

	Grain finess number	Clay content	Starch content	Moisture content	Pouring Temperature
1	1	2	1	1	1
2	2	1	1	1	1
3	2	2	1	1	1
4	2	2	1	2	1
Total of level 1	**1**	**1**	**4**	**3**	**4**
Total of level 2	**3**	**3**	**0**	**1**	**0**

From Table 5-19, the total conditions of level 1 and level 2 can indicate the best condition for using. The high clay content, which causes too high compressive strength will be a disadvantage for ramming off; thus, low clay content should be selected. Thus, the best condition is coarse grain, low clay content, low starch content and low moisture content for pouring with low temperature. Actually, the other three conditions in Fig. 5-19 are available for using with zero defect. Both Fig. 5-18 and 5-19 show the same most significant factors which are starch and pouring temperature. The pouring temperature is the most important cost in the process. The conclusion should be summarized from technical possibility and actual possibility, and the reduction of defect and cost saving should be determined together.