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Problem Analysis at a Semiconductor Company: A Case Study on IC Packages

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Abstract: Integrated Circuits (IC) are used in applications such as power supply, mobile phones, lighting, computing, consumer and automotive applications. Defects are a main concern in the IC packages making industry as these could occur at various stages of production and result in huge losses. Problem solving tools have been used to identify the causes of the defects and to formulate practical solutions for the problems. These may include relatively simple visual tools like the Ishikawa diagram and stratification, statistical tools like the Pareto analysis, or more technical tools like the Taguchi design of experiments. This paper demonstrates the effective use of such tools in a semiconductor company and charts the route of a problem analysis to reduce defects. It will be shown that the effectiveness of the process stems from a logical approach which facilitates replication in other departments. The project focused on one major process involving the most valuable IC package in the production where the defects were caused by the machine parameter, process flow, compound type and other non-human causes.

Key words: Defects, problem solving, fish-bone, pareto, taguchi

INTRODUCTION

The semiconductor company in this case study is a leading international provider of IC packages that powers the products consumers use every day. The company was facing one of its greatest challenges. Defects have occurred in daily production and affect the daily production of IC packages in end of line as shown in Fig. 1. Some of the types of defects are voids, cracks, incomplete mold, fail stand-off height, broken package and marking defects. Appropriate actions are needed to identify root causes, workout and execute solutions. The management decided to confine the project on the end of line process of micro department. The lessons learnt from this pilot project will be implemented in other projects involving other departments. For effective problem analysis, it is important to follow a logical approach using specific tools to arrive at root causes. At each stage, a tool is chosen for the appropriate circumstances to generate answers. These answers may then generate other questions or clues on the problem analysis trail and other sets of answers are found. This investigative process continues until the root causes are finally determined. It should be noted that choosing the wrong tool at any stage on the problem analysis trail may lead to dead ends (Kumar and Sosnoski, 2009; Ho, 1993; Gwiazda, 2006; Hagemeyer *et al*., 2006). As a simple guide to choosing the appropriate tool, one should begin to understand the outcome of using any particular problem solving tool and the information that is available at the time to make the use of the tool applicable (Bruce, 1990; Juran, 2009). For example the Ishikawa Diagram is used to identify many possible causes for a known effect or problem.

It organizes ideas into helpful categories that are used to identify possible causes for a problem. Stratification is a technique used in combination with other data analysis tools. When data from a variety of sources or categories have been lumped together, the meaning of the data can be impossible to see. This technique separates the data so that patterns can be seen. The process map or flow chart is one of the oldest, simplest and most valuable techniques for depicting and organizing work. It is used to show the sequence of events to build a product. The pareto analysis is a statistical technique that is used for the selection of a limited number of tasks which produce significant overall effect. It employs the 20/80 rule, the idea that by doing 20% of the work one can generate 80% of the benefit of doing the whole job. Or in terms of problem analysis, a large majority of problems or defets (80%) are actually caused by a few vital causes (20%) (Juran, 2009). Another

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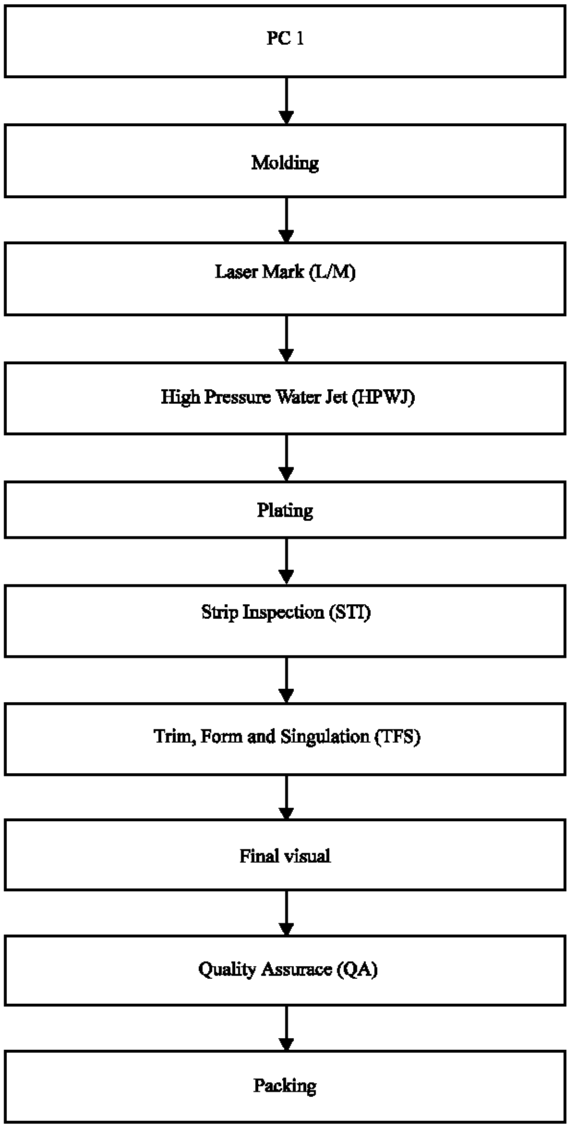

Fig. 1: Process for IC packages in end of line

useful problem analysis tool, the Taguchi method, can be employed as a mechanism for evaluating and implementing improvements in products, processes, materials, equipment and facilities. As a result of studying the key parameters that control a process, improvements can be realised for desired characteristics that can substantially reduce the number of defects (Klein, 1996; Anthony, 2006; Tong *et al*., 1997). The tools mentioned thus far, were used to analyse the problem, identify possible causes and formulate solutions to effectively reduce the defects in the IC packages.

MATERIALS AND METHODS

The overall methodology has been summarized in Fig. 2. IC packages were inspected under 30x scopes after each process and the data of defects were collected. The data for IC packages with the most defects were stratified to highlight patterns if any in the defects. Next, pareto analysis was carried out to segregate major contributing defects categories. The Ishikawa diagram was then used to draw out possible causes for the major defect. To understand the effect of the combination of contributing parameters for the identified possible cause, the Taguchi

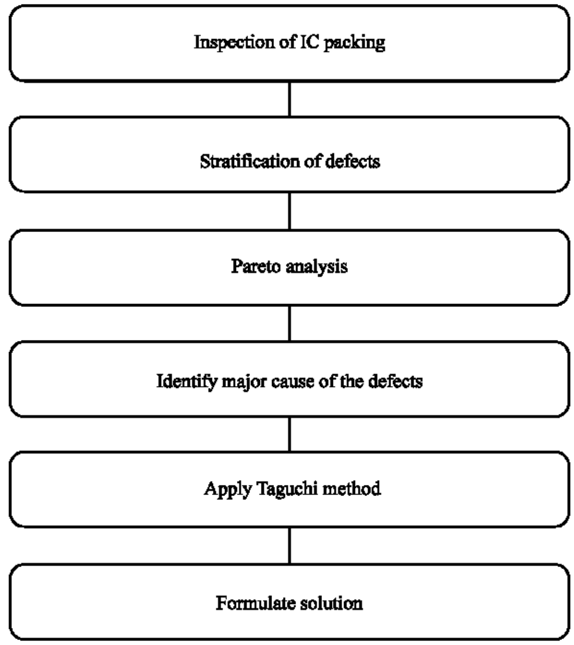

Fig. 2: Methodology

Table 1: L25 Orthogonal Array

Expt.	P1	P2	P3	P4	P5	P6
1	1	1	1	1	1	1
2	1	2	2	2	2	2
3	1	3	3	3	3	3
4	1	4	4	4	4	4
5	1	5	5	5	5	5
6	2	1	2	3	4	5
7	2	2	3	4	5	1
8	2	3	4	5	1	2
9	2	4	5	1	2	3
10	2	5	1	2	3	4
11	3	1	3	5	2	4
12	3	2	4	1	3	5
13	3	3	5	2	4	1
14	3	4	1	3	5	2
15	3	5	2	4	1	3
16	4	1	4	2	5	3
17	4	2	5	3	1	4
18	4	3	1	4	2	5
19	4	4	2	5	3	1
20	4	5	3	1	4	2
21	5	1	5	4	3	2
22	5	2	1	5	4	3
23	5	3	2	1	5	4
24	5	4	3	2	1	5
25	5	5	4	3	2	1

Table 2: Values of parameters set for each experiment

Expt No.	Mold temp (°C)	Clamp pressure (Ton)	Transfer pressure (kg cm^{-2})	Transfer speed (sec)	Cure time (sec)	Hot plate temp. (°C)
1	170	40	85	7.0	90	150
2	170	48	88	8.6	96	154
3	170	56	91	10.2	102	158
4	170	64	94	11.8	108	162
5	170	72	97	13.4	114	166
6	172	40	88	10.2	108	166
7	172	48	91	11.8	114	150
8	172	56	94	13.4	90	154
9	172	64	97	7.0	96	158
10	172	72	85	8.6	102	162
11	174	40	97	13.4	96	162
12	174	48	94	7.0	102	166
13	174	56	97	8.6	108	150
14	174	64	85	10.2	114	154
15	174	72	88	11.8	90	158
16	176	40	94	8.6	114	158
17	176	48	97	10.2	90	162
18	176	56	85	11.8	96	166
19	176	64	88	13.4	102	150
20	176	72	91	7.0	108	154
21	178	40	94	13.4	102	154
22	178	48	97	13.4	108	158
23	178	56	85	7.0	114	162
24	178	64	88	8.6	90	166
25	178	72	91	10.2	96	150

method was then employed. Experiments were conducted with 6 parameters and 5 levels. The appropriate orthogonal array is L25 as shown in Table 1.

For the experiment, the following factors are assumed:

- Other variables besides mold parameters are assumed constant
- The experiments are carried out on a fixed auto mold machine
- The surrounding condition is assumed to be constant
- The same operator was assigned to operate the machine
- The experiment is conducted on dummy frame (without die)

The conditions set for each experiment are listed in Table 2.

RESULTS AND DISCUSSION

The result from defects inspection of all the packages is summarized in Table 3. Three IC packages, 6SOT23M, 5SC70M and 6SC70M were identified to have the highest number of defects. These 3 packages in fact make up a substantial 70% of the company output from Micro End-of-Line and therefore deserves more focus. To facilitate a closer inspection of the 3 packages, stratification was employed. Figuer 3-5 summarize the stratification exercise.

Table 3: Defects according to package type

Package type	No. of defects (ppm)
3SOT23	7
SOT143	4
5SOT23	8
5TSOT23M	10
6TSOT23M	10
5SOT23M	14
6SOT23	5
6SOT23M	27
8SOT23	8
3SC70	7
4SC70	9
5SC70M	21
6SC70M	23
SC79	8
Total	143

From the 3 stratification charts above, the defects were categorized into process specified defects. As shown in Table 4, 5 and 6, there are only 5 manufacturing processes in micro end of line. These are molding, laser mark, high pressure water jet, plating and trim, form and singulation. The others are inspection and packing processes. Defects such as incomplete mold, void, fail vertical offset, flashes, compound leaking, flake surface and unclean package are categorized under molding processes defects. Lead width, fail stand-off height, bent lead, missing lead and no forming are categorized under trim, form and singulation process defects. Marking defect comes under its own category and originates from the laser marking process. While chip, dented lead, crack and broken package is categorized under other group because

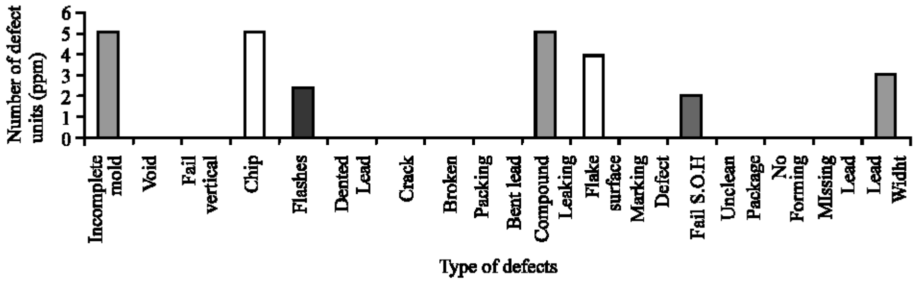

Fig. 3: Stratification of defects for 6SOT23M

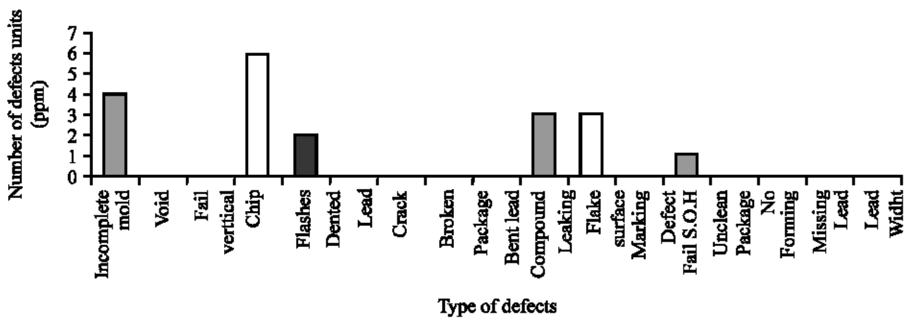

Fig. 4: Stratification of defects for 5SC70M

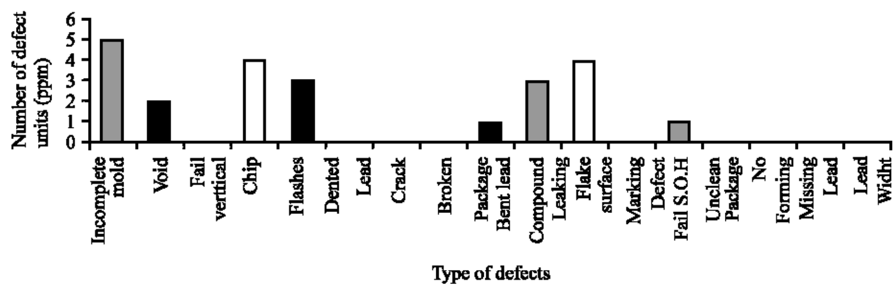

Fig. 5: Stratification of defects for 6SC70M

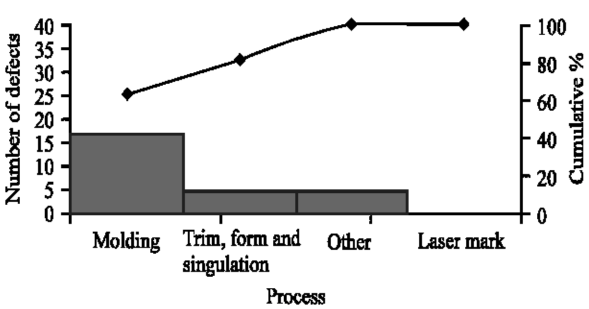

Fig. 6: Pareto diagram of defects for 6SOT23M

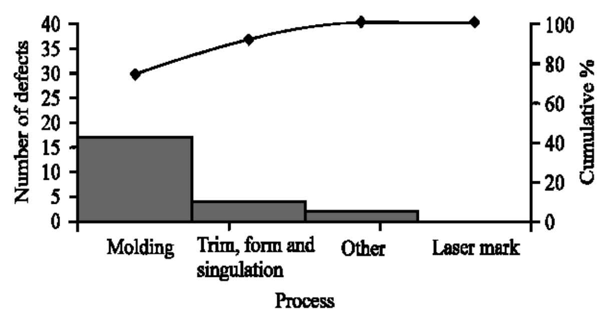

Fig. 7: Pareto diagram of defects for 5SC70M

Table 4: Pareto table of defects for 6SOT23M

Process	Number of defects	Percent of total	Cumulative percent
Molding	17	62.96	62.96
Trim, Form and Singulation	5	18.52	81.48
Other	5	18.52	100.00
Laser Mark	0	0	100.00
Total	27	100.00	100.00

Table 5: Pareto table of defects for 5SC70M

Process	Number of defects	Percent of total	Cumulative percent
Molding	12	57.14	57.14
Other	6	28.57	85.71
Trim, form and Singulation	3	14.29	100.00
Laser mark	0	0	100.00
Total	21	100.00	100.00

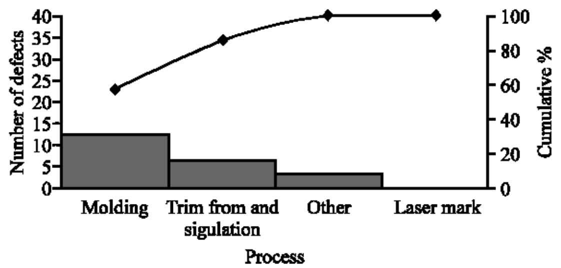

Fig. 8: Pareto diagram of defects for 6SC70M

Table 6: Pareto table of defects for 6SC70M

Process	No. of defects	Percent of total	Cumulative percent
Molding	17	73.91	73.91
Other	4	17.39	91.30
Trim, form and Singulation	2	8.70	100.00
Laser mark	0	0.00	100.00
Total	23	100.00	100.00

Table 7: Consequences when mold parameter out of control

Mold parameters	Status	Consequences
Mold temperature	Too low	The mold compound will not melt completely. Sticking and incomplete mold happen.
	Too high	Chip package and flake surface will happen.
Clamp pressure	Too low	Compound leaking, flashes on lead will happen.
	Too high	No effect.
Transfer pressure	Too low	Incomplete mold, void and chip package will happen.
	Too high	Wire of the units will sweep easily and compound leaking will happen.
Transfer speed	Too low	Incomplete mold, void and chip package will happen.
	Too fast	Incomplete mold and wire of the units will sweep easily.
Cure time	Too short	Sticking, incomplete mold and void will happen.
	Too long	Sticking and chip package will happen easily.
Hot plate temperature	Too low	Temper lead will happen.
	Too high	Temper lead will happen.

these defects can be caused by various processes or combination of a few processes.

Using the Pareto analysis, it was also observed that molding is the process that contributes most to the defects of the 3 types of packages which cover 62.96% of 6SOT23M, 57.14% of 5SC70M and 73.91% of 6SC70M as shown in Fig. 6, 7 and 8. Therefore, the company then decided to look at the molding process in more detail as out of control mold parameters produce consequences as shown in Table 7.

Ishikawa analysis of incomplete mold of 6SOT23M drew out possible causes. These were verified as shown in Table 8. To optimize the mold parameters the Taguchi method was employed. The results of the experiment are shown in Table 9.

It can be seen that experiment No. 15 has the lowest defect number yield. This mold parameters configuration was suggested to be used instead of the current mold parameters because it yields the least number of defects. Shown below is the sample calculation and tabulation of the SN ratio.

$$S_{m1} = \frac{(305+350+389)^2}{3} = 363.312 \quad (1)$$

$$S_{T1} = 305^2 + 350^2 + 389^2 = 366.846 \quad (2)$$

$$S_{e1} = S_{T1} - S_{m1} = 366.846 - 363.312 = 3.534 \quad (3)$$

$$V_{e1} = \frac{S_{e1}}{N-1} = \frac{3.534}{2} = 1.767 \quad (4)$$

$$SN_1 = 10\log\frac{(1/N)(S_{m1} - V_{e1})}{V_{e1}} = 10\log\frac{(1/3)(363.312 - 1.767)}{1.767} = 18.3 \quad (5)$$

Table 8: Verification of possible causes for incomplete mold of 6SOT23M

Causes	Valid	Description
Wrong corrective measurement	No	The preview corrective measurement is correct according to procedure.
Wrong inspection data	No	The inspection data for 6SOT23M is correct.
Material compound expired	No	The compound used is not yet expired.
Cleaning compound expired	No	The cleaning compound used is not yet expired.
Wrong operating method or sequence	No	The correct operating method is used and the correct procedure is carried out on time.
Room humidity out of control	No	The room humidity for the past 1 month is within range. (30-80%)
Room temperature out of control	No	The room temperature for the past month is within allowable range. (15°C-28°C)
New operators	No	Experience operator is operating the 6SOT23M machine
Understaffed operators	No	The number of operator is sufficient.
Machine maintenance is not carried out according to schedule	No	The maintenance is carried out according to schedule.
Mold parameters not optimized	Yes	The mold parameters have not been reviewed in last 12 months.

Table 9: Data collected from experiments

Expt.	Mold temp. (°C)	Clamp pressure (ton)	Transfer pressure (kg cm^{-2})	Transfer speed (sec)	Cure time (sec)	Hot plate temp (°C)	Trial 1	Trial 2	Trial 3	Mean
							(ppm)			
1	170	40	85	7.0	90	150	305	350	389	348
2	170	48	88	8.6	96	154	296	304	288	296
3	170	56	91	10.2	102	158	108	117	123	116
4	170	64	94	11.8	108	162	58	68	75	67
5	170	72	97	13.4	114	166	89	94	78	87
6	172	40	88	10.2	108	166	213	241	197	217
7	172	48	91	11.8	114	150	187	198	173	186
8	172	56	94	13.4	90	154	194	209	191	198
9	172	64	97	7.0	96	158	148	134	123	135
10	172	72	85	8.6	102	162	124	119	108	117
11	174	40	97	13.4	96	162	258	287	298	281
12	174	48	94	7.0	102	166	214	187	199	200
13	174	56	97	8.6	108	150	200	188	194	194
14	174	64	85	10.2	114	154	124	107	96	109
15	174	72	88	11.8	90	158	25	35	48	36
16	176	40	94	8.6	114	158	104	97	120	107
17	176	48	97	10.2	90	162	145	159	125	143
18	176	56	85	11.8	96	166	89	77	68	78
19	176	64	88	13.4	102	150	56	58	48	54
20	176	72	91	7.0	108	154	45	35	49	43
21	178	40	94	13.4	102	154	123	114	108	115
22	178	48	97	13.4	108	158	98	87	76	87
23	178	56	85	7.0	114	162	81	72	63	72
24	178	64	88	8.6	90	166	98	84	70	84
25	178	72	91	10.2	96	150	56	42	40	46

Table 10: SN ratio values

Expt	Mold temp. (°C)	Clamp pressure (ton)	Transfer pressure (kg cm^{-2})	Transfer speed (sec)	Cure time (sec)	Hot plate temp. (°C)	Trial 1	Trial 2	Trial 3	SN
							(ppm)			
1	170	40	85	7.0	90	150	305	350	389	18.3
2	170	48	88	8.6	96	154	296	304	288	31.4
3	170	56	91	10.2	102	158	108	117	123	23.7
4	170	64	94	11.8	108	162	58	68	75	17.9
5	170	72	97	13.4	114	166	89	94	78	20.5
6	172	40	88	10.2	108	166	213	241	197	19.8
7	172	48	91	11.8	114	150	187	198	173	23.4
8	172	56	94	13.4	90	154	194	209	191	26.2
9	172	64	97	7.0	96	158	148	134	123	20.6
10	172	72	85	8.6	102	162	124	119	108	23.1
11	174	40	97	13.4	96	162	258	287	298	22.7
12	174	48	94	7.0	102	166	214	187	199	23.4
13	174	56	97	8.6	108	150	200	188	194	30.2
14	174	64	85	10.2	114	154	124	107	96	17.7
15	174	72	88	11.8	90	158	25	35	48	9.7
16	176	40	94	8.6	114	158	104	97	120	19.1
17	176	48	97	10.2	90	162	145	159	125	18.4
18	176	56	85	11.8	96	166	89	77	68	17.4
19	176	64	88	13.4	102	150	56	58	48	20.2
20	176	72	91	7.0	108	154	45	35	49	15.5
21	178	40	94	13.4	102	154	123	114	108	23.6
22	178	48	97	13.4	108	158	98	87	76	17.9
23	178	56	85	7.0	114	162	81	72	63	18.0
24	178	64	88	8.6	90	166	98	84	70	15.5
25	178	72	91	10.2	96	150	56	42	40	14.4

The other values of SN ratio are calculated as above and tabulated in the Table 10. The response table to calculate an average SN value for each factor is shown in Table 11.

A sample calculation for Factor B (Clamp Pressure) is shown below:

$$SN_{B1} = \frac{(18.3+19.8+22.7+19.1+23.6)}{5} = 20.7$$

$$SN_{B2} = \frac{(31.4+23.4+23.4+18.4+17.9)}{5} = 22.9$$

$$SN_{B3} = \frac{(23.7+26.2+30.2+17.4+18.0)}{5} = 23.1$$

$$SN_{B4} = \frac{(17.9+20.6+17.7+20.2+15.5)}{5} = 18.4$$

Table 11: Average SN values

Expt.	Mold temperature (A)	Clamp pressure (B)	Transfer pressure (C)	Transfer speed (D)	Cure time (E)	Hot plate temperature (F)	SN
1	1	1	1	1	1	1	18.3
2	1	2	2	2	2	2	31.4
3	1	3	3	3	3	3	23.7
4	1	4	4	4	4	4	17.9
5	1	5	5	5	5	5	20.5
6	2	1	2	3	4	5	19.8
7	2	2	3	4	5	1	23.4
8	2	3	4	5	1	2	26.2
9	2	4	5	1	2	3	20.6
10	2	5	1	2	3	4	23.1
11	3	1	3	5	2	4	22.7
12	3	2	4	1	3	5	23.4
13	3	3	5	2	4	1	30.2
14	3	4	1	3	5	2	17.7
15	3	5	2	4	1	3	9.7
16	4	1	4	2	5	3	19.1
17	4	2	5	3	1	4	18.4
18	4	3	1	4	2	5	17.4
19	4	4	2	5	3	1	20.2
20	4	5	3	1	4	2	15.5
21	5	1	5	4	3	2	23.6
22	5	2	1	5	4	3	17.9
23	5	3	2	1	5	4	18.0
24	5	4	3	2	1	5	15.5
25	5	5	4	3	2	1	14.4

Table 12: Values of SN and ranking

Level	Mold temperature (A)	Clamp pressure (B)	Transfer pressure (C)	Transfer speed (D)	Cure time (E)	Hot plate temperature (F)
1	22.4	20.7	18.9	19.2	17.6	21.3
2	22.6	22.9	19.8	23.9	21.3	22.9
3	20.7	23.1	20.2	18.8	22.8	18.2
4	18.1	18.4	20.2	18.4	20.3	20.0
5	17.9	16.6	22.7	21.5	19.7	19.3
Δ	4.7	6.5	3.8	5.5	5.2	4.7

$$SN_{B5} = \frac{(20.5+23.1+9.7+15.5+14.4)}{5} = 16.6$$

$$\Delta = Max - Min = 23.1 - 16.6 = 6.5$$

The value of SN for each factor and value of the effect of the factor is shown in Table 12. It can be seen that clamp pressure has the largest effect on the defect number and transfer pressure has the smallest effect on defect number.

The effect of this factor is then calculated by determining the range.

CONCLUSION

The processes in Micro End of Line produced a certain amount of defects. The problem analysis identified all the defects and categorized them into different categories as well as reported the identified possible causes. The investigation zoomed into the molding process because the evidence showed this process was contributing the most defects. The use of the Ishikawa Diagram and the Taguchi method successfully identified the more critical parameters as well as the best parameter configuration that produced the least number of defects. It can therefore be concluded that the mentioned problem analysis tools can be effectively used to reduce the number of defects in IC packages provided they are employed appropriately.

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