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Temperature Stable Solder Pastes – Properties and Reliability

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Anotace:

Tento článek se zabývá použitím teplotně stabilních pájecích past, což je jedním ze současných trendů v technologii pájení. Zmíněné pasty není nutné skladovat v chladničce a ani nemusejí být před použitím temperovány na pokojovou teplotu. Na současném trhu lze nalézt několik značek teplotně stabilních pájecích past. Tento článek popisuje návrh a realizaci experimentů zaměřených na ověření výrobci deklarovaných vlastností těchto past. Tyto experimenty byly zároveň navrženy a realizovány dle metodiky "Design of Experiments". V závěru tohoto článku jsou prezentovány výsledky a doporučení pro použití těchto past v praxi.

Abstract:

This article deals with one of the newest trends in soldering that means a using of the temperature stable solder pastes. These pastes do not need to be stored in fridge and do not need to be tempered to the room temperature before their use. On the market, several brands of temperature stable solder pastes are available. The article describes designed and performed experiments which aim to verify the declared properties. The experiments were designed and performed according Design of Experiments methodology. The results and recommendation for practice are presented at the end of the article.

INTRODUCTION

The most common technology used for conductive connection of components with substrates in electronic devices is soldering. In this technology, many articles and improvements were performed. Many articles are associated mainly with the issues of upgrading to lead-free soldering. Because of the new materials use, it is necessary once again to optimize the whole soldering process. We can find a lot of research works on this subject, for example optimization of the soldering profile [1], drying of solder paste before printing or soldering [2] and the flux used in solder paste [3].

One of the newest trends in soldering is using of the temperature stable solder pastes. These pastes do not need to be stored in fridge and do not need to be tempered to the room temperature before their use. These properties are a big advantage, but also bring the necessary compromise of other properties. Requirements for storage and processing conditions were based on the experience and especially on identified defects. Identified defects were just formed by failure to comply with the required conditions.

For the broad application, the temperature stable solder pastes must be verified. The issue can be simply divided into three areas. At first, it is necessary to verify an influence of these solder pastes on printing process. Than we should also verify an influence on result of reflow process. Finally, we must not forget to verify the solder joint reliability.

In this context, the different failures in process of solder paste printing can occur (e.g. spreadability of paste, wrong shape of printed paste, too many or not enough of printed paste, place of printed paste). Another failure can occur in soldering process (e.g. voids, shorts, tombstoning, solder balling, solder beading, whiskers, and solder grapping). The elimination of these failures occurrence or at least the minimization of these failures is a goal of every electronic device manufacturer. It follows that the temperature stable solder pastes should be investigated before the use in production for specific application. [4]

On the market, several brands of temperature stable solder pastes are available. Are all pastes really suitable for all applications? That is a question. Therefore, the experiment with temperature stable solder pastes was designed and performed with using DOE (Design of Experiments) methodology [5].

MATERIALS AND PROCEDURES

The many different failures can be made during the process of paste printing and reflowing. These failures are influenced by solder paste. In present, the standard solder pastes SAC 305 are used in the manufacturing company in West Bohemia. This company want to use temperature stable solder pastes in production. The aim of the following experiment is to recommend the suitable temperature stable solder paste for using in this company.

The nineteen temperature stable solder pastes were chosen in the first step of the experiment. These pastes are from different suppliers but all of them are SAC 305 with composition 96,5% Sn – 3% Ag – 0.5% Cu (Type 4). All pastes are temperature stable pastes and therefore the storage at a refrigerator is not necessary. The parameters of these pastes were compared from datasheets and evaluated by points. The overall points for each paste were compared and the three best pastes were chosen for the next step of the experiment.

The pastes chosen for the second step of the experiment were AIM M8, KOKI S3X48-M406 ECO, Loctite GC10. Also the paste Indium 8.9HF was chosen for this experiment. This paste is standard paste and was chosen as a reference sample for comparison of all properties between temperature stable solder pastes and standard paste.

Stencil printing was used to apply solder pastes onto the printed circuit boards in this step of the experiment. The device Horizon 03ix from DEK Company was used for the application. The stencil for this device was made galvanically and the thickness of this stencil was 100 µm.

Tab. 1: Printing process parameters of solder pastes.

Squeegee length [mm]	250
Squeegee pressure [kg]	7 (8 for GC10)
Printing rate [mm/s]	50
Separation rate [mm/s]	3
Air temperature [°C]	22,5 - 23,5
Relative humidity [%]	40 - 43

The device SPI KY8030-2 from KOH YOUNG Company was used for control of printing process. This device can display the 3D model of the solder paste and can evaluate the indicator Process Capability – Cp. Insufficient samples were removed from the process and the results of this check were recorded and can be seen in Fig. 16.

The surface mounters YAMAHA YS12 and YAMAHA YS24 were used for mounting of the SMD chip components.

All samples were reflowed, after the mounting process, in the continuous reflow oven Heller 1809 MKIII with nine heating zone and two cooling zone. For the experiment, two different soldering profiles were used. The first (short) profile and second (long) profile can be seen in Fig. 1, Fig. 2 and Tab. 2.

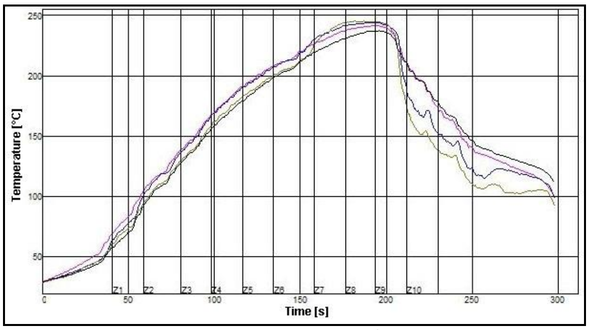


Fig. 1: Short soldering profile – S.

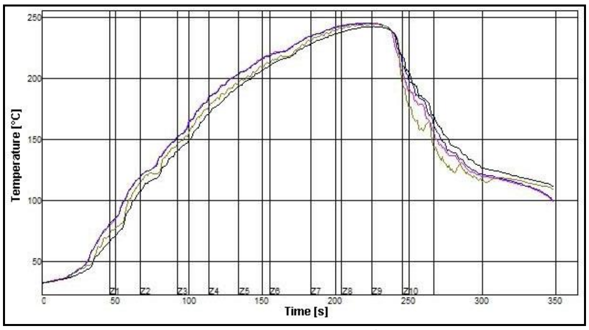


Fig. 2: Long soldering profile – L.

Tab. 2: Set parameters for reflow oven for both profiles.

Short temperature profile (S)	
Belt speed: 86 cm/min	
Zone	Temperature [°C]
1	135
2	150
3	175
4	215
5	220
6	235
7	250
8	255
9	250
10	130
11	100

Long temperature profile (L)	
Belt speed: 70 cm/min	
Zone	Temperature [°C]
1	135
2	150
3	175
4	220
5	225
6	240
7	250
8	255
9	250
10	100
11	110

In the first experiment in second step, the stencil life of pastes was compared. Each paste was printed by the device Horizon 03ix on hundred PCBs in nine series (see Tab. 3). Each other series was printed in defined time after the previous series. The stencil was automatically cleaned by vacuum cleaning and dry towel after each sample. The defects after printing process founded by the solder paste inspection were evaluated.

Tab. 3: Design of the first experiment

No. of series	1	2	3	4	5	6	7	8	9
Pause before print [min]	0	2	4	6	8	10	15	30	90
Overall time of paste on stencil [min]	0	2	6	12	20	30	45	75	165

The comparison of solder pastes with considering of overall quality of solder joint was aim of the second experiment in the second step. This experiment was prepared according Design Of Experiment (DOE) methodology, see Tab. 4. The defects after soldering process were observed and evaluated. The twenty PCBs were mounted and soldered for each option, it follows that in overall 320 PCBs were soldered.

Tab. 4: Design of the second experiment

	Solder paste	Temperature profile	Pause before print
1	(1) Loctite GC 10	(1) Short	(1) 0 min
2			(2) 15 min
3		(2) Long	(1) 0 min
4			(2) 15 min
5	(2) KOKI M406 ECO	(1) Short	(1) 0 min
6			(2) 15 min
7		(2) Long	(1) 0 min
8			(2) 15 min
9	(3) AIM M8	(1) Short	(1) 0 min
10			(2) 15 min
11		(2) Long	(1) 0 min
12			(2) 15 min
13	(4) Indium 8.9HF	(1) Short	(1) 0 min
14			(2) 15 min
15		(2) Long	(1) 0 min
16			(2) 15 min

In the third (last) step the reliability of soldered joints was investigated. The mechanical strength of the joints was measured immediately after reflow process, after thermal aging and after shock aging.

In all experiments, the fourteen parameters were measured or monitored. The results were converted to points between 0 and 1. Zero points has the paste with worst parameter. One point has the paste without failures (if the parameter defect was expressed by count of occurrences) or the paste with the best parameter. All pastes received the relative number of points. After this process, the significant coefficients were set for each parameter (5 – Bridges; 4 – Beads, Balls; 3 – Print defects, voids count, voids area; 2 – Cp; 1 – mechanical strengths). The points were multiplied by the relative coefficients and the results were counted for each paste. Then the overall points for each paste were calculated for printing process, soldering process and reliability. At the end, the overall average points for each paste were used for determination of the best temperature stable solder paste in all respects.

Tab. 5: Results of the second and third experiment.

Test No.	Solder paste	Temp. profile	Pause before print	Bridges (QFN 0,4)	Solder beads	Avg. Solder balls	F QFN04 [N]	FAGING QFN04 [N]	F SOT2 [N]	FAGING SOT2 [N]	Count of voids	Area of the voids [%]	Cp volume	Cp height	Cp area
1	(1) Loctite GC10	Short	0	16	3	4,21	248,19	225,17	35,6	32,73	57	34,02	1,5945	1,519	3,187
2			15	8	6	8,85	242,52	208,05	35,9	33,44	56	36,38			
3		Long	15	18	3	10,1	238,75	216,1	35,9	32,82	49	28,77			
4			0	16	2	13,95	237,7	213,22	35,6	32,67	57	27,97			
5	(2) KOKI M406 ECO	Long	0	2	0	1,6	248,98	220,45	37,2	33,38	22	17,98	1,6147	1,774	2,773
6			15	0	0	3,65	241,67	237,68	37,2	34,05	23	15,26			
7		Short	15	2	0	9,3	245,55	235,27	36	34,12	33	16,43			
8			0	9	0	8,55	251,85	217,62	35,9	33,69	29	12,46			
9	(3) AIM M8	Short	0	0	0	3,7	264,82	231,41	34,3	32,63	13	4,36	1,7681	1,945	2,253
10			15	0	0	4,1	266,72	236,24	33,7	32,53	13	8,67			
11		Long	15	0	0	2,7	245,62	238,9	36,4	33,15	26	10,5			
12			0	1	1	1	252,92	235,78	35,4	31,46	24	7,67			
13	(4) Indium 8.9HF	Long	0	0	0	6,9	237,85	222,82	36,6	32,86	32	2,18	1,647	1,757	2,179
14			15	2	1	9,3	248,93	244,28	36,7	32,87	31	3,56			
15		Short	15	1	1	13,1	241,7	246,61	36,1	32,8	22	8,96			
16			0	0	0	20	259,48	251,98	36,4	33,46	30	2,113			

RESULTS AND DISCUSSION

The results of the first experiment can be seen in Tab. 6. Each PCB was checked by SPI device and every pad with insufficient paste amount was signed as defect. All defects were founded in the last series only (paste was 165 minutes on the stencil). The pastes AIM and KOKI has worse results. The paste Indium has the best result without defects. This result is very surprising because this paste is not temperature stable.

Tab. 6: Results of the first experiment – number of defects.

Solder paste	Loctite GC10	KOKI M406 ECO	AIM M8	Indium 8.9HF
No. of defects	1	20	145	0

The results of the second experiment can be seen in Tab. 5.

Each PCB was observed and checked by SPI device after reflowing process. The bridges were founded in QFN components with 0.4 mm pitch only. The other components were without bridges. The number of bridges in Tab. 5 is number of bridges founded in all samples. In Fig. 3, the boxplot diagram of bridges amount for each solder paste can be seen. In Fig. 4, the influence of input factors on bridges creation can be also seen, e.g. the value of temperature profile for Loctite paste is 5 above the zero line, it follows that if the long profile is set, the amount of bridges is more about 5 bridges than if the short profile is set. The value of pause for Loctite paste is 3 under the zero line, it follows that if the 15minutes pause is used, the amount of bridges is less about 3 bridges than if the pause is not used (0 minutes).

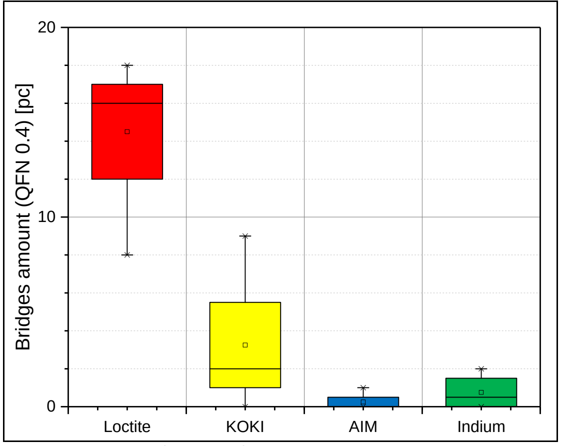


Fig. 3: Influence of paste type on bridges creation.

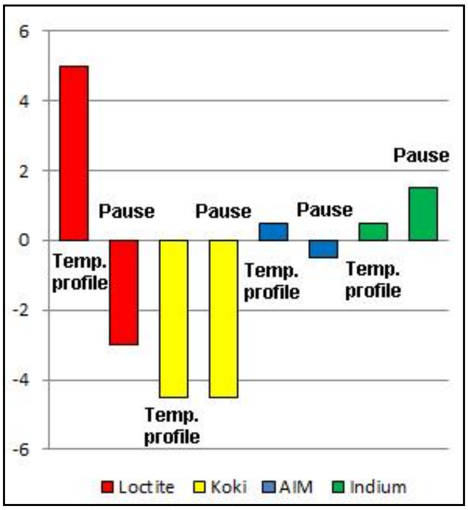


Fig. 4: Influence of input factors on bridges creation.

The solder beads were founded under the 0603 and 0402 chip components only. The other components were without solder beads. In Fig. 5, the boxplot diagram of solder beads amount for each solder paste can be seen. In Fig. 6, the influence of input factors on solder beads creation can be seen.

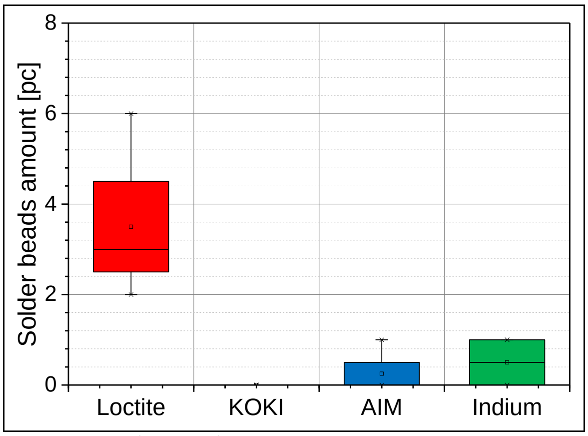


Fig. 5: Influence of paste type on solder beads creation.

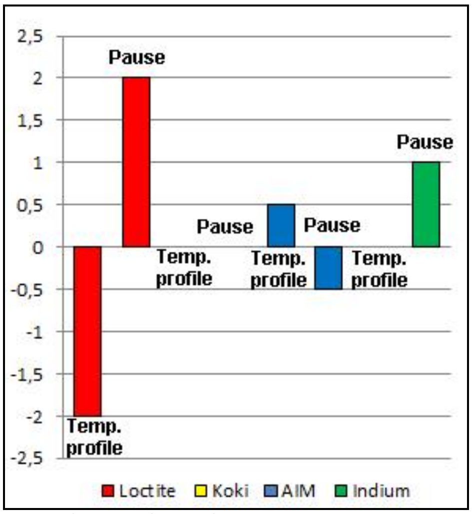


Fig. 6: Influence of input factors on solder beads creation.

The solder balls were observed in the area of two SOT 23 components only for simplifying of observing. All solder balls in these areas (see Fig. 7) were counted. In Fig. 8, the boxplot diagram of average solder balls amount for one PCB of each solder paste can be seen. In Fig. 9, the influence of input factors on solder balls creation can be seen.

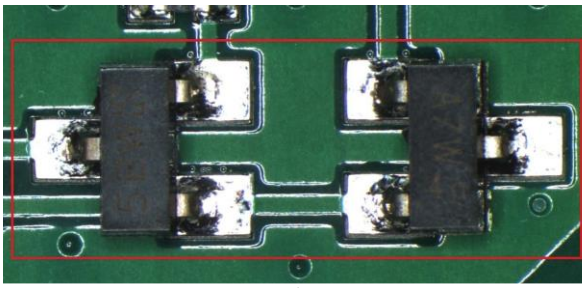


Fig. 7: The observed area of two SOT-23 components.

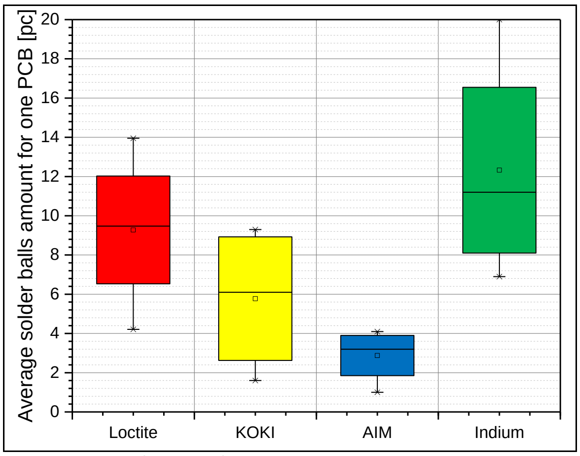


Fig. 8: Influence of paste type on solder balls creation.

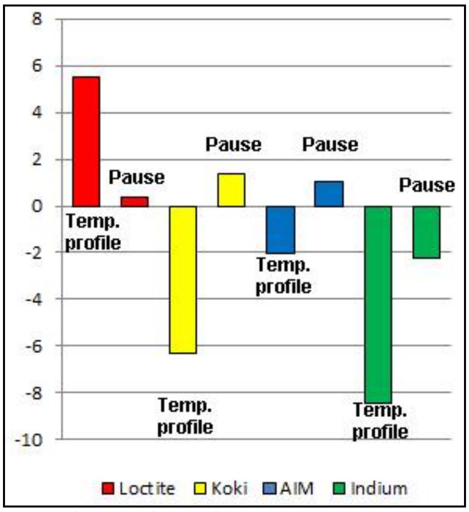


Fig. 9: Influence of input factors on solder balls creation.

The mechanical shear strength was measured for QFN components with 0.4 mm pitch and for SOT-23 components before aging, after accelerated aging (125°C / 1000 hours) and after shock aging (1000 cycles – 1 cycle = 105°C/30 minutes and -40°C/30 minutes). In figures (Fig. 10, Fig. 12), the boxplot diagrams of maximal shear strengths for each solder paste without aging and with aging's can be seen. In Fig. 11 and Fig. 13, the influence of input factors on the mechanical shear strength can be seen.

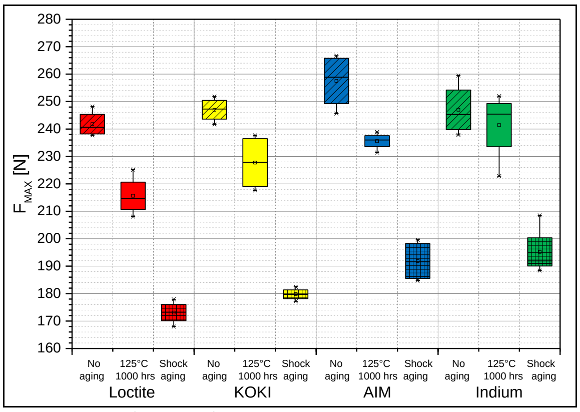


Fig. 10: Influence of paste type and aging on mechanical shear strength for QFN components.

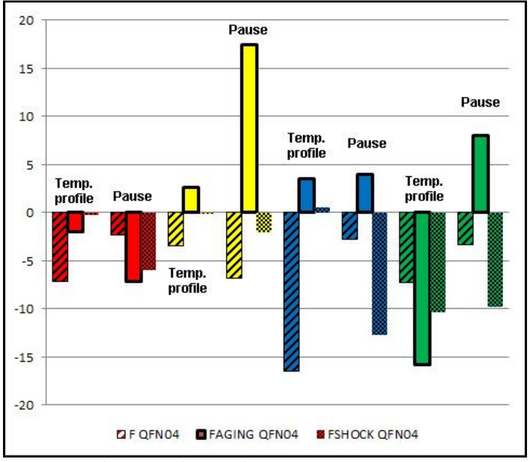


Fig. 11: Influence of input factors on mechanical shear strength for QFN components.

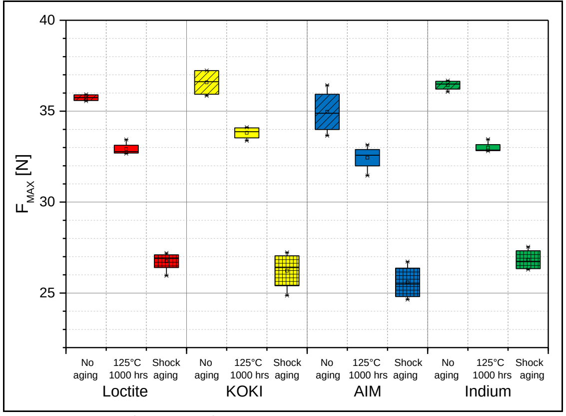


Fig. 12: Influence of paste type and aging on mechanical shear strength for SOT-23 components.

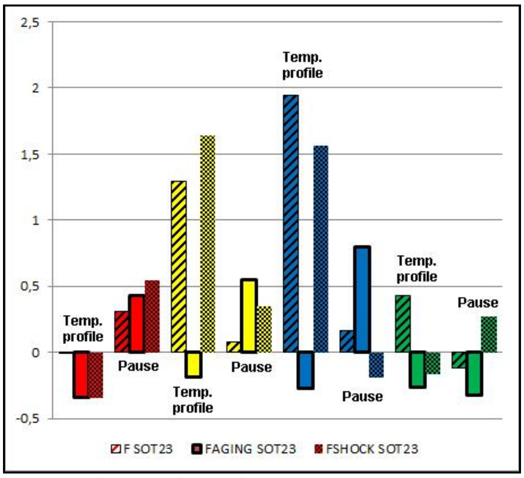


Fig. 13: Influence of input factors on mechanical shear strength for SOT-23 components.

The amount and area of voids in solder joint is important factor but it is not easy to observe it. The one of the best method for the observing of voids is X-RAY observation [4]. In the experiment, the QFN components were also observed by X-RAY inspection machine and the main (middle) contacts of these components were investigated. The software ImageJ was used for evaluation of voids count and voids area for each sample. The average amount of voids for one component was calculated and these values can be seen in Fig. 14. In Fig. 15, the influence of input factors on the average count of voids and average area of voids can be seen.

As it was said, the process capability indicators (Cp) were measured by the device SPI KY8030-2. These indicators for each paste are shown in Fig. 16. The most stable paste in volume and height is AIM paste and the most stable paste in area is Loctite paste.

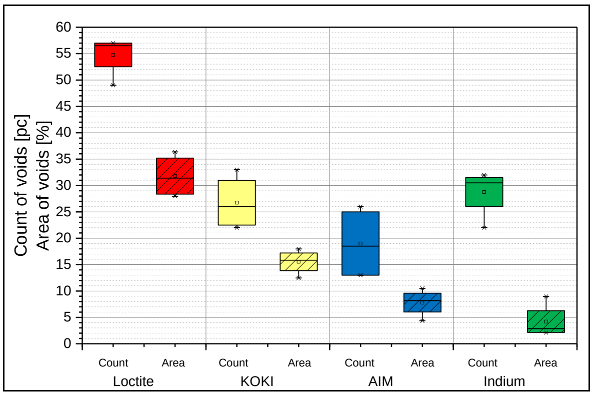


Fig. 14: Influence of paste type on count of voids and area of voids.

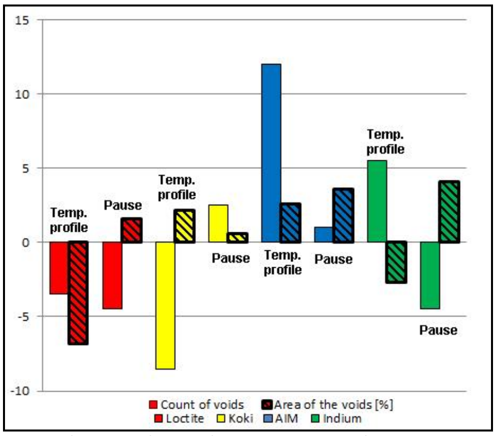


Fig. 15: Influence of input factors on count of voids and area of voids.

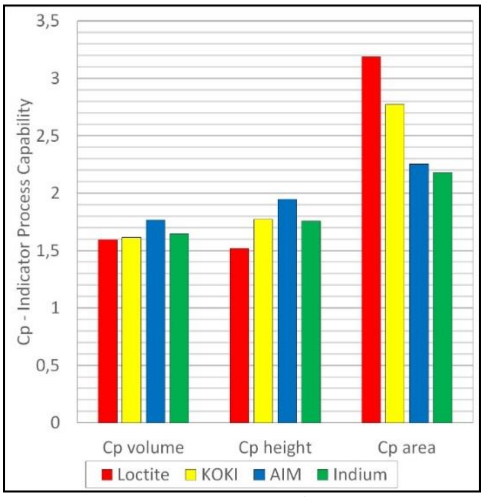
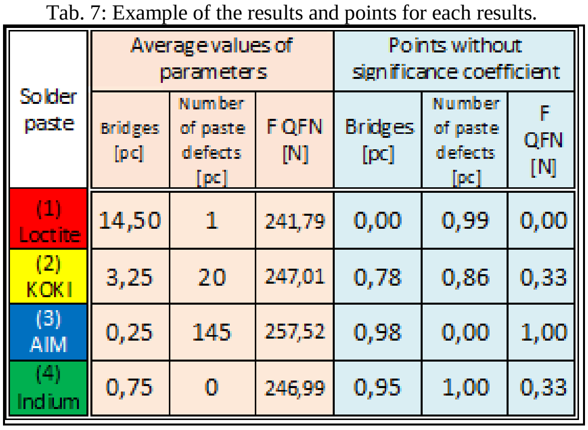


Fig. 16: Printing process capability for used solder pastes.

At the last step, the all measured parameters were converted to points between 0 and 1 (example of the conversion is in blue part of Fig. 16), the significance coefficients were set. The points were multiplied with coefficients and overall points for the printing process (Tab. 8), soldering process (Tab. 9) and reliability (Tab. 10) were calculated.

At the end, the overall points were summed and then divided by 3. This average shows the overall points for each paste and the quality of paste from the tested aspects.

Tab. 7: Example of the results and points for each results.



Solder paste	Average values of parameters			Points without significance coefficient		
	Bridges [pc]	Number of paste defects [pc]	F QFN [N]	Bridges [pc]	Number of paste defects [pc]	F QFN [N]
(1) Loctite	14,50	1	241,79	0,00	0,99	0,00
(2) KOKI	3,25	20	247,01	0,78	0,86	0,33
(3) AIM	0,25	145	257,52	0,98	0,00	1,00
(4) Indium	0,75	0	246,99	0,95	1,00	0,33

Tab. 8: Results of soldering process with reflecting of significance coefficient.

Solder paste	Bridges (5)	Solder beads (4)	Avg. solder balls (4)	Count of voids (3)	Area of the voids (3)	Cp volume (2)	Cp height (2)	Cp area (2)	**Overall soldering points**
(1) Loctite	0,00	0	1	0	0	0	0	2	**3,00**
(2) KOKI	3,90	4	2,12	1,53	1,53	0,24	1,2	1,18	**15,70**
(3) AIM	4,90	3,72	3,08	1,95	2,25	2	2	0,14	**20,04**
(4) Indium	4,75	3,44	0	1,41	2,61	0,6	1,12	0	**13,93**

Tab. 9: Results of printing process with reflecting of significance coefficient.

Solder paste	Number of paste defects (3)	**Overall printing points**
(1) Loctite	2,97	**2,97**
(2) KOKI	2,58	**2,58**
(3) AIM	0	**0,00**
(4) Indium	3	**3,00**

Tab. 10: Results of reliability testing with reflecting of significance coefficient.

Solder paste	F QFN (1)	FAGING QFN (1)	FSHOCK QFN (1)	F SOT (1)	FAGING SOT (1)	FSHOCK SOT (1)	**Overall reliability points**
(1) Loctite	0	0	0	0,48	0,34	0,93	**1,75**
(2) KOKI	0,33	0,47	0,3	1	1	0,51	**3,61**
(3) AIM	1	0,77	0,85	0	0	0	**2,62**
(4) Indium	0,33	1	1	0,91	0,41	1	**4,65**

Tab. 11: Overall average results with reflecting of significance coefficient.

Solder paste	**Overall printing points**	**Overall soldering points**	**Overall reliability points**	**Average of points**
(1) Loctite	**2,97**	**3,00**	**1,75**	**2,57**
(2) KOKI	**2,58**	**15,70**	**3,61**	**7,30**
(3) AIM	**0,00**	**20,04**	**2,62**	**7,55**
(4) Indium	**3,00**	**13,93**	**4,65**	**7,19**

CONCLUSION

The main goal of this article was to test new type of solder pastes that are presented as thermally stable solder paste, compare their properties with the conventional type of solder pastes and recommend for using in production.

Four samples of solder paste were tested. Three of them were representatives thermally stable solder paste and the fourth sample was paste, which must be stored at low temperature. As part of the testing one experiment was performed, which focused on the printing properties of solder pastes. The second experiment was focused on the evaluation of solder joints quality with SMD components. The input factors in this experiment were used solder paste, time before printing and used soldering profile. Defect occurrence and mechanical strength were evaluated after a reflow process.

From the results of the experiments a lower potential to the formation of microballs are evident for the temperature stable solder pastes in comparison with the conventional paste. On the contrary, Indium 8.9HF paste, representative of conventional solder pastes, surprised during the first experiment. No defect was found after printing process by SPI.

Based on collected data during the experiment and their subsequent evaluation, we can recommend temperature-stable solder paste AIM M8 and KOKI S3X48-M406ECO that had the best results from all the tested samples.

The recommendation of the best solder paste depends on the significance of parameters settings. This significance was chosen in the manufacturing company and for this company the solder pastes KOKI M406 ECO and AIM M8 could be recommended. For using of the results in other companies, the significance coefficients could be readjusted and the results have to be recalculated.

ACKNOWLEDGEMENTS

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