ASSEMBLY AND SOLDERING PROBLEMS IN LEAD-FREE THROUGH HOLE REFLOW TECHNIQUE

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Through hole, reflow THR is a technique that allows through-hole components to be soldered, together with SMD *(Surface Mount Device*) in the same reflow soldering process. The investigation results of lead-free THR manufacturing process were shown in this paper. The test boards containing different SMT passive and active components as well as components dedicated to the THR technique were used in the investigation. The influence of solder paste printing process as well as lead-free reflow soldering process on solder joints quality were reported. The obtained results have shown that parameters of the both above-mentioned processes are the most crucial in SMT containing THR technique.

Keywords: THR, SMD, lead free solder paste

1. INTRODUCTION

Through hole reflow (THR), pin-in-hole reflow, intrusive reflow, pin-in-paste reflow and multi-spot soldering are all terms used to describe the same reflow process that allows through-hole components to be soldered together with SMD in the same reflow soldering process neither without the need for hand soldering, nor wave soldering or of a selective soldering system [1-3]. The THR technique bases on reflow soldering can reduce the cost of lead-free technology and some of the process defects by eliminating or minimizing number of soldering processes, materials and equipment essential for assembly of electronic products.

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The great challenge in the THR process is stencil design and printing process. The stencil must deliver the correct amount of solder paste to the through-holes in the stencil printing process to form acceptable joints after reflow. To achieve this goal, the amount of solder needed must be determined. Also stencil printing process parameters should be optimized because it balances between the requirements for traditional surface mount components and through-hole components [4].

Obviously the THR components need to be able to withstand the temperature of the lead-free reflow process. This information should be available from the component vendor specification sheets. Their leads should be rounded at the end and they need the correct length to form a good solder joint. THR components should be mounted correctly in holes and the orientation of the component in the reflow oven should also be taken into consideration [4].

The correct lead-free soldering profile for THR technique is also the great challenge. It has to meet soldering requirements both for very small surface mount components and sometimes very large and massive THR components which are neighbors on the same PCB *(Printed Circuit Board)*.

The investigation results of lead-free THR manufacturing process of special designed test board will be shown in the paper. The influence of solder paste printing and reflow soldering processes on solder joints quality will be reported in more details.

2. MATERIALS, MAIN EQUIPMENT AND PROCESSES USED DURING INVESTIGATION

The test boards containing different sizes (0201 to 1206) passive and active SMD as well as four different types of components dedicated to the THR technique were used in the investigation (Fig.1).

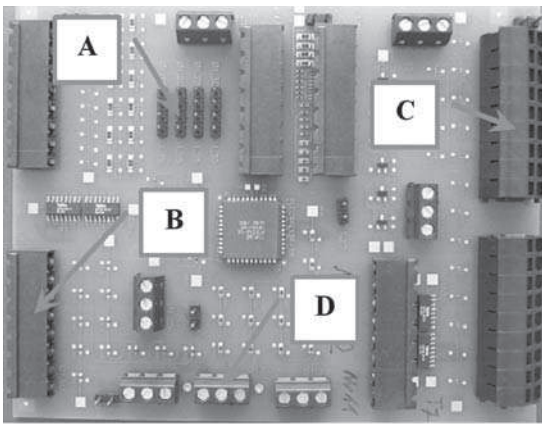

Fig. 1. An example of a test board and marks of four types of THR components used in the investigation.
Rys. 1. Przykład płytki testowej i oznaczenia czterech typów podzespołów THR użytych w badaniach.

The PCB contains two types of hole sizes for THR components: „small" and „big". The „small" size – is the hole size recommended by components producer; the „big" ones – are holes increased by 0.1 mm increased in comparison to the „small" ones. All components had Sn coating on terminations or leads.

A solder paste containing the SnAg3.0Cu0.5 (SAC305) alloy and the ROL0 type flux was used during investigations. The solder paste was printed on test boards' pads via 125 or 150 µm thick steel stencil. The printing results were assessed by the 3D inspection system Vision Master AP (Fig. 2) and X-ray technique.

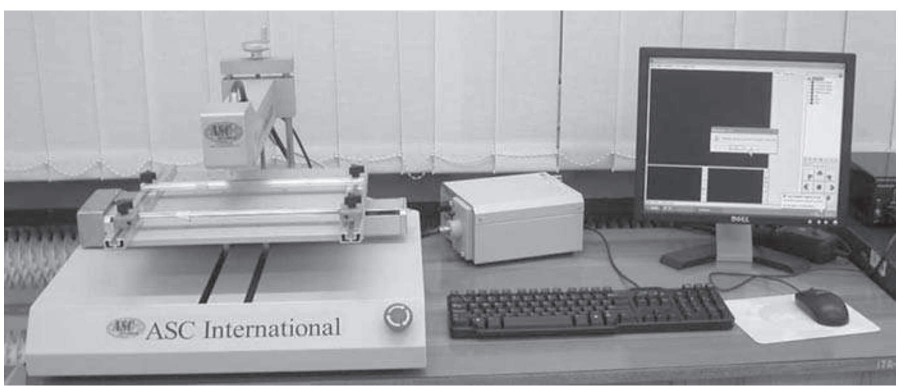

Fig. 2. 3D inspection system Vision Master AP.
Rys. 2. System do inspekcji 3D Vision Master AP.

Next SMD components were placed on pads with solder paste using the FUJI AIM pick & place machine (Fig. 3) and after that THR components were added by hand. Finally test boards were soldered using the convection oven VIP70A made by BTU, which has 5 heating zones independently regulated from bottom and from top (Fig. 3).

Fig. 3. SMT production line at the ITR: the FUJI AIM pick & place machine – left; convection oven VIP70A - right.
Rys. 3. Linia produkcyjna do SMT: automat montażowy FUJI AIM – od lewej; piec konwekcyjny VIP70A – od prawej.

The external appearance of solder joints was assessed using the Automatic Optical Inspection (AOI) system 22XDL made by Marantz (Fig. 4).

Fig. 4. AOI system 22XDL.
Rys. 4. System AOI 22XDL.

The internal structure of solder joints was investigated in turn by X-ray technique using the Nanomex 180 NF X-ray unit (Fig.5) manufactured by Phoenix/X-Ray as well as cross-sections of chosen solder joints were executed.

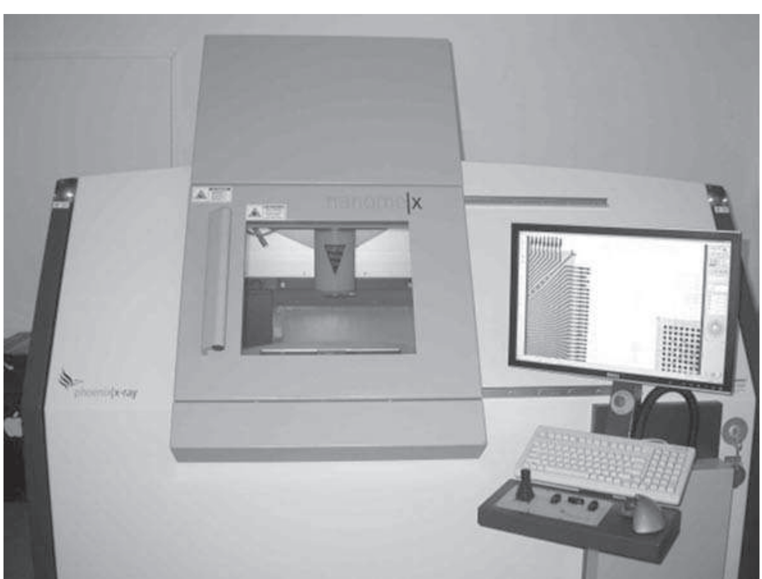

Fig. 5. Nanomex 180 NF X-ray unit.
Rys. 5. Urządzenie rentgenowskie Nanomex 180 NF.

3. ASSEMBLY PROCESS

The assembly process of test boards consists from three parts: solder paste printing operation for SMD and inside holes for THR components simultaneously, pick, place operation of SMD and then THR components, finally reflow soldering operation in which solder paste melt, and solder joints would be created.

The printing and soldering processes were performed based on Taguchi's Method of experiment designing [5]. The quantitative influence of different factors on solder joints quality manufactured by THR technique could be checked in this way. The main factors were put in the Taguchi's orthogonal array $L_8(2^7)$ (Tab.1) according with linear graph presented on Fig. 6.

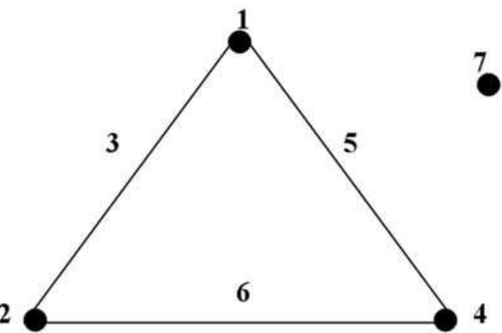

Fig. 6. Linear graph used for the Taguchi's orthogonal array L_8 (2^7).
Rys. 6. Graf liniowy wykorzystany do utworzenia tablicy L_8 (2^7) Taguchiego.

Table 1. A part of the Taguchi's orthogonal array L_8 (2^7) containing main factors.
Tabela 1. Część tablicy ortogonalnej Taguchiego L_8 (2^7) zawierająca czynniki główne.

Experiment No.	Levels of main factors			
	1 – stencil thickness	2 – overprint repetition	4 – soldering profile	7 – holes size
T1	125 µm	1x	profile 1	small"
T2	125 µm	1x	profile 2	"big"
T3	125 µm	2x	profile 1	"big"
T4	125 µm	2x	profile 2	"small"
T5	150 µm	1x	profile 1	"big"
T6	150 µm	1x	profile 2	"small"
T7	150 µm	2x	profile 1	"small"
T8	150 µm	2x	profile 2	"big"

The list of chosen main factors covered: 1 – stencil thickness (125 μm and 150 μm); 2 - number of solder paste printing process repetition (1x and 2x); 4 – soldering profiles (profile 1 and 2) and 7 – holes dimension in PCB for THR components („small" and „big"). The full Taguchi's orthogonal array L_8 (2^7) contained also interactions 3, 5 and 6, between main factors as shows the linear graph on Fig. 6. The three PCBs per experiment were manufactured.

3.1. Printing process

The solder paste was printed on test boards' pads via 125 or 150 μm thick stencils according to the experiment schedule presented before. The printing results were assessed by the 3D inspection system and X-ray technique. They show that quality of solder paste printing, in situation where both small SMD and THR components are present on the PCB, are significantly relate with type of components. Some printing parameters adequate for THR components (e.g. 150 μm stencil thickness, 2x overprint repetitions) are completely inadequate for small SMD (Fig. 7). The solder paste quantity on pads for R0201 was too small.

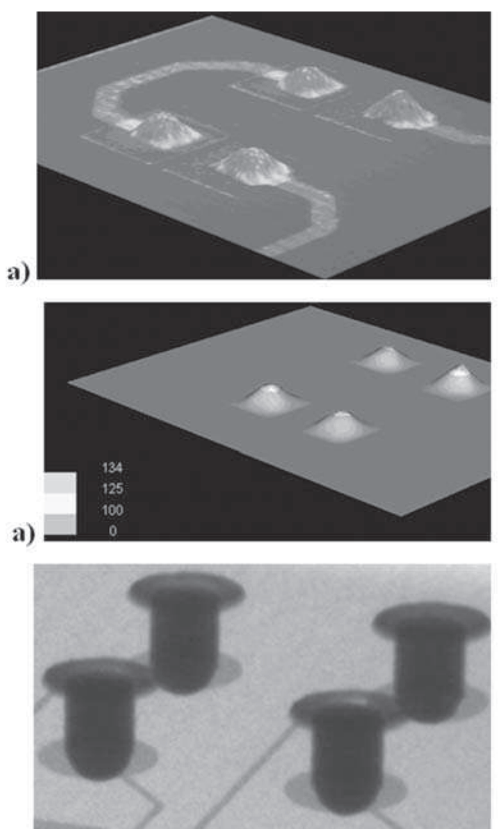

Fig. 7. Results of printing process (150 μm stencil thickness and 2x overprint repetitions) for: a) resistors R0201; b) THR component "C".

Rys. 7. Wyniki procesu druku (grubość szablonu 150 μm, nadruk dwukrotny) dla: a) rezystorów R1206; b) elementów THR "C".

The best compromise results for all components on the test board were obtained using thinner stencil (125 μm) and two repetitions of overprint during solder paste printing process. The quantity of solder paste was acceptable as well for holes for THR components as on pads for smaller and bigger SMD (Fig. 8).

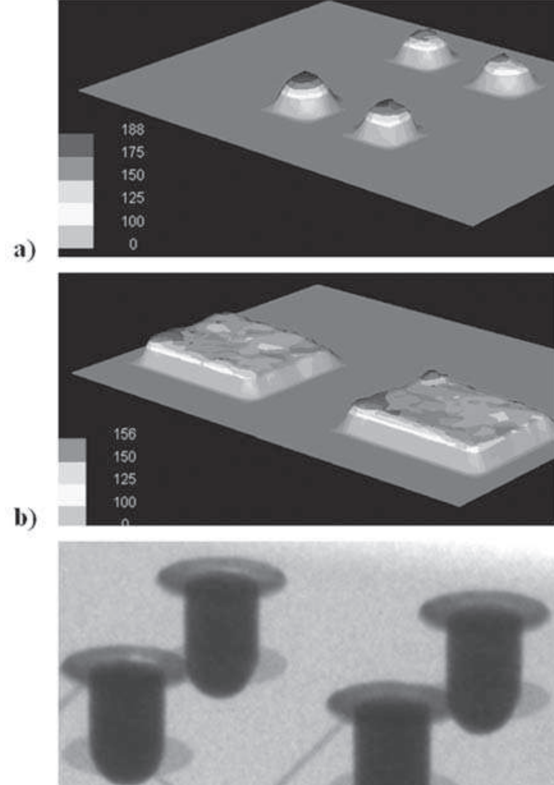

Fig. 8. Results of printing process (125 μm stencil thickness and 2x overprint repetitions) for: a) resistor R0201; b) R0603; c) THR component "C".
Rys. 8. Wyniki procesu druku (grubość szablonu 125 μm, nadruk dwukrotny) dla: a) rezystorów R1206; b) R0603; c) elementów THR "C".

3.2. Pick & place process of THR components

SMD components were placed on solder paste using production equipment for SMT as was mentioned at the second paragraph. The THR components were then added to PCB by hand during these first trials with THR technique. The automatic pick & place process of THR components will be investigate in this year.

No observed significant difficulties during hand operated pick & place process of THR components. Slightly bigger holes diameters were essential in THR technique in comparison to wave soldering requirements. The holes diameters recommended by THR components producer were correct for hand operated pick & place process. They enable correct placing components into holes and sticking components leads by solder paste (Fig. 9).

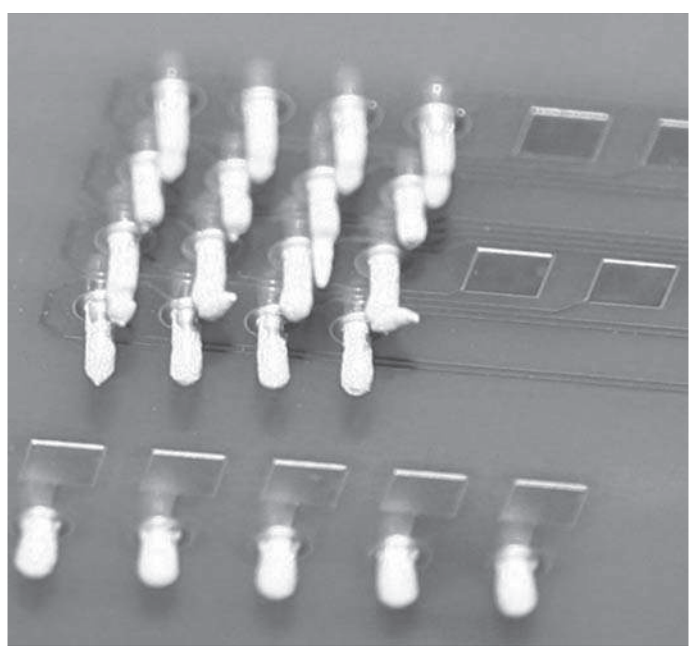

Fig. 9. Results of pick & place process of THR components “A” and “B”.
Rys. 9. Wyniki osadzania elementów THR “A” i „B”.

3.3. Soldering process

Test boards containing through-hole components together with SMD were reflow soldered using two types of lead-free soldering profiles (Fig. 10-11).

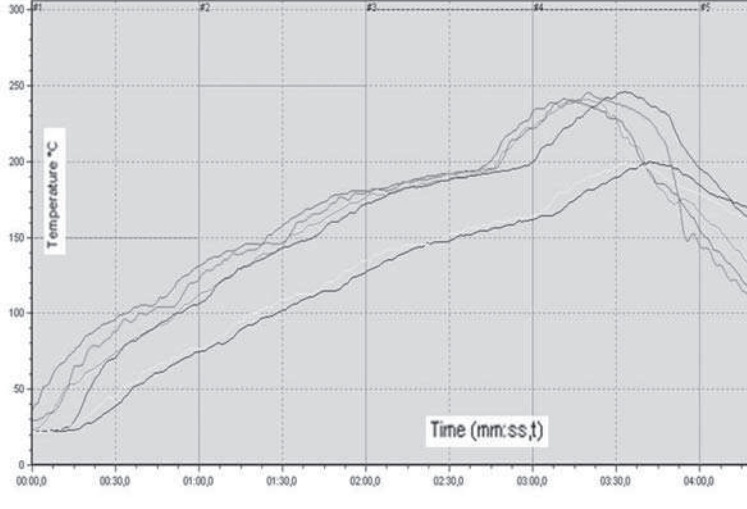

Fig. 10. The shape of the “profile 1”.
Rys. 10. Kształt “profilu 1”.

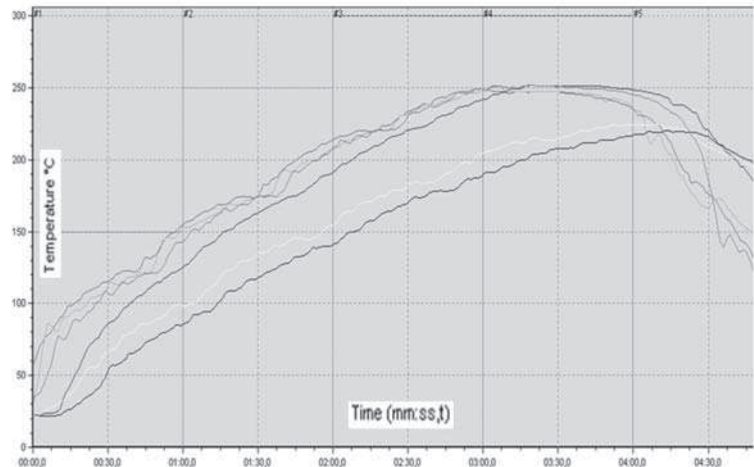

Fig. 11. The shape of the "profile 2".
Rys. 11. Kształt "profilu 2".

The "Profile 1" (Fig.10) characterized with soldering time (time above liquidus 217°C) since 37 to 50 s and peak temperature since 241 to 246°C for all components except THR component "C", for which 199°C peak temperature was obtained only. The THR component "C" had the highest thermal capacity from all components on the PCB.

The "Profile 2" (Fig.11) characterized soldering time since 115 to 130 s and peak temperature since 249 to 252°C for all components except THR component "C". For THR component "C" obtained soldering time 29 s and peak temperature 220°C in the middle of component "C" and soldering time 49 s and peak temperature 225 °C on edge pad of the "C" THR component. Both soldering profiles weren't optimal for the test board and further investigations are requiring in this subject.

4. RESULTS OF THR SOLDER JOINTS ASSESSMENT

4.1. AOI results

The Automatic Optical Inspection (AOI) was used in THR solder joints external appearance assessment. The assessment criteria were shown in Fig. 12. The average results of AOI THR solder joints assessment for each experiment made by Taguchi's method were presented in Tab. 2

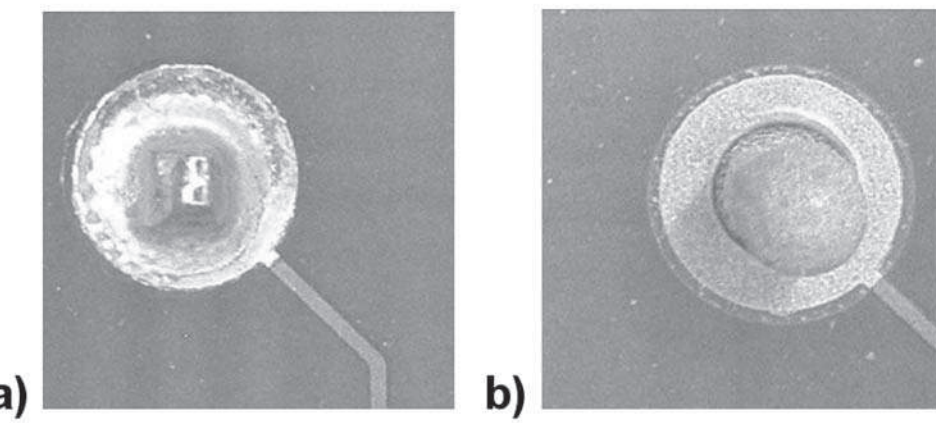

Fig. 12. Assessment criteria used in AOI assessment of THR solder joints: a) correct; b) fail.
Rys. 12. Kryteria oceny połączeń lutowanych elementów THR zastosowane w AOI: a) prawidłowe; b) nieprawidłowe.

Table 2. The AOI results of THR solder joints assessment for experiments made by Taguchi's method.
Tabela 2. Wyniki oceny AOI połączeń lutowanych elementów THR wykonanych w eksperymentach wykonanych metodą Taguchiego.

Experiment No.	Levels of main factors				Quantity of correct THR solder joints [%]
	1 – stencil	2 – over-print	4 – profile	7 – holes	
T1	125 μm	1x	profile 1	"small"	17.8
T2	125 μm	1x	profile 2	"big"	15.9
T3	125 μm	2x	profile 1	"big"	45.5
T4	125 μm	2x	profile 2	"small"	55.6
T5	150 μm	1x	profile 1	"big"	13.6
T6	150 μm	1x	profile 2	"small"	31.1
T7	150 μm	2x	profile 1	"small"	37.8
T8	150 μm	2x	profile 2	"big"	68.2

The AOI results were next used in analyze of variance (ANOVA) which was a next part of Taguchi's method design of experiment. The results of ANOVA analyzes were presented in Tab. 3 and in Fig. 13.

Table 3. ANOVA results of THR solder joints assessment.
Tabela 3. Wyniki analizy wariancji oceny połączeń lutowanych elementów THR.

Factor	SSx	v	V	F	SS'	P [%]
1	31,69	1	31,69	2,61	-	-
2	2071,18	1	2071,18	170,32***	2059	74
1x2	4,69	1	4,69	0,39	-	-
3	393,71	1	393,71	32,38**	381	14
1x3	196,79	1	196,79	16,18**	185	7
2x3	77,36	1	77,36	6,36*	65	2
4	0,11	1	0,11	0,01	-	-
T	2775,52	7	----	----	2775	100
e_p	36,48	3	12,16	----	85	3

*- 90%; ** - 95%; *** - 99% - levels of significance.

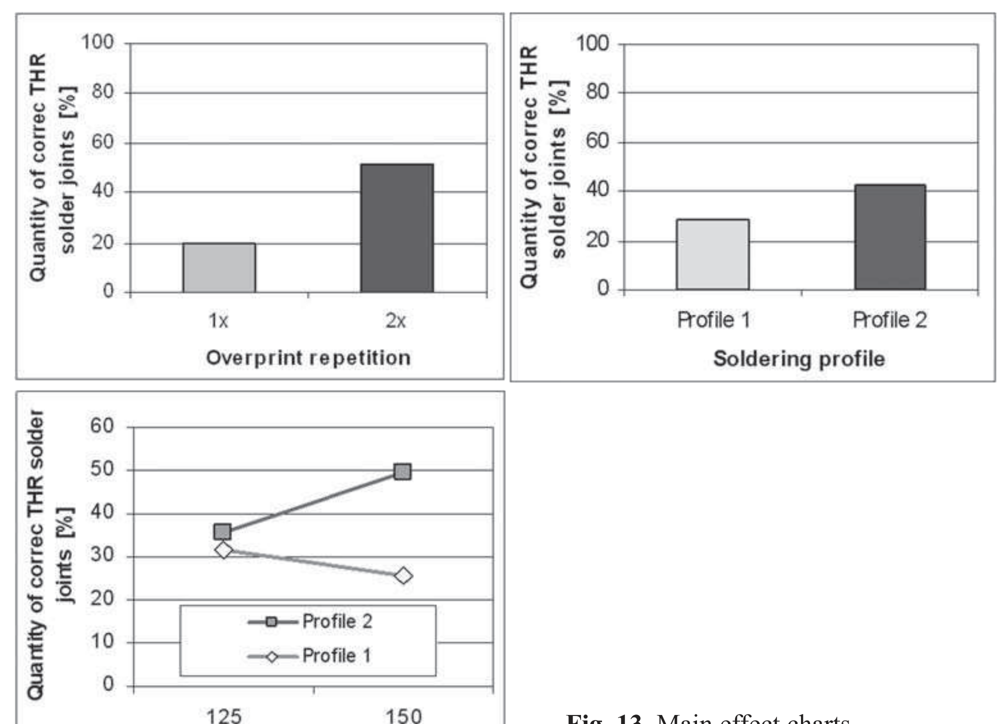

Fig. 13. Main effect charts.
Rys. 13. Wykresy efektów głównych.

The highest influence on THR solder joints quality has number of solder paste overprints. The two solder paste overprints were much better than one. The second important factor was soldering profile. The profile with longer soldering time and higher peak temperature was better. It allows to soldered partially the THR "C" component also, what effected on analyze results improvement. The interaction between soldering profile and stencil thickness was observed also. The "profile 2" was much better for solder joints manufactured using the 150 μm stencil.

4.2. X-Ray and cross-section results

The internal structure of THR solder joints was checked also by X-ray technique as well as cross-sections for all types of THR components from each experiment were made. These results confirm main relations obtained during AOI investigations. They showed that in THR technique the main difficulties are related with big THR components present on PCB, like component "C", having high thermal capacity (Tab. 4). Such components require much longer soldering time and higher peak

Table 4. Examples of THR solder joints internal structure.
Tabela 4. Przykłady wewnętrznej struktury połączeń lutowanych elementów THR.

Experiment No. – THR component	X-Ray results	Cross-section results
T1 – "A"		
T1 – "C"		
T4 – "A"		
T4 – "C"		

temperature, but applied temperature has to be safe for different components at the same time. The both applied soldering profiles were acceptable for all SMD and THR components except component „C". No degradation of small SMD solders joints during investigation was observed.

Authors think that for the investigated test board convection, reflow oven with more than 5 heating zones is essential to optimize soldering profile and to solve problems with THR component „C". The less complicated PCBs, than used in investigations, can be soldered in lead-free Through Hole Reflow Technique using 5-zones convection, reflow ovens.

5. SUMMARY

The obtained results have shown that solder paste printing and reflow soldering are the most crucial processes in SMT containing THR technique. Also big THR components having high thermal capacity present on PCB together with very small SMD components are large challenge for SMT technologies.

The thinnest as possible stencils, but assuring correct quantity solder paste at holes, two solder paste overprints during solder paste printing process and soldering profile having as long as possible soldering time and as high as possible peak temperature are recommended in lead-free SMT with THR technique by authors. The convection, reflow oven with more than 5 heating zones could help to optimize soldering profile for high-tech PCBs with THR components. No complicated PCB containing THR components having small thermal capacity can be soldered using typical lead-free soldering profiles and 5-zones, convection, reflow ovens.

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PROBLEMY MONTAŻOWE I LUTOWNICZE W BEZOŁOWIOWEJ TECHNICE LUTOWANIA ROZPŁYWOWEGO ELEMENTÓW PRZEWLEKANYCH

THR jest techniką lutowania, która umożliwia jednoczesne lutowanie rozpływowe elementów przewlekanych i SMD. W artykule przedstawiono wyniki badań bezołowiowego procesu THR. Podczas badań wykorzystano płytki testowe zawierające różnorodne elementy SMD oraz podzespoły dedykowane do techniki THR. Zbadano wpływ procesu nadruku pasty lutowniczej oraz bezołowiowego procesu lutowania rozpływowego na jakość połączeń lutowanych. Wyniki badań ukazały, że parametry obu wspomnianych wyżej operacji są bardzo istotne w SMT zawierającej technikę THR.

Słowa kluczowe: THR, SMD, bezołowiowa pasta lutownicza