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Effect of Reflow Profile (RSP Vs RTP) on Sn/Ag/Cu Solder Joint Strength in Electronic Packaging

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Abstract: Reflow profile parameter with reducing soaking time promising better solder joint performance to the semiconductor package. Hence, this paper study lead-free solders joint strength using two different reflow profile; conventional ramp-soak-peak (RSP) and ramp to peak (RTP) for solder ball attachment. In this project, Sn/3.8Ag/0.7Cu on Ni/Au surface finish were reflow at peak temperature 245±5°C with optimized soak time conducted in a seven zone forced convection oven. Ball shears testing along with failure mode analysis –ductile and brittle failure mode were used to assess solder joint strength as reflow, after multiple reflow and high temperature storage test (HTS). Intermetallic thickness was measured using Image Analyzer. Elemental analysis by EDX detected Cu-Sn phase at IMC peak and Cu-Ni-Sn phase presented at IMC interface. As a result, Sn/3.8Ag/0.7Cu using RTP profile has better solder joint strength than RSP with carried out 100% ductile failure mode. RTP profile has been established as a benchmark of industry standard. This profile has much shorter soak time during flux activation temperature at 130°C to 170°C to prevent flux dry-up and hence enable better flux activation during solder joint formation at peak temperature zone. This will enhance an even intermetallic growth and a stronger & more reliable solder joint.

Keywords: intermetallic, reflow profile, ramp-soak-peak, ramp-to-peak, shear strength

1.0 INTRODUCTION

The reflow profile is defined as the relationship of temperature versus time during heating. Consequently, it is a critical part of the solder process and must provide adequate time for flux volatilization, pullback, proper peak temperatures and time above liquidus (TAL). A typical reflow profile is made up four distinct zones: Preheat zone, soak zone, reflow zone and cooling zone.

The soak zone is intended to bring the temperature of the entire board to a uniform temperature to minimize temperature gradients. The flux is one of the main constituents of the solder paste vehicle and is activated during the soak zone of the solder reflow profile. The flux activators promote wetting of the molten solder to the surface mount lands and component termination or leads by removing oxide and other surface contaminants. The type of flux has a direct impact on the cleanliness of the assembly. The wetting action of the paste is determined by the activity of its flux. Typically, soak times are around the range of 130-170°C for 60-90 seconds [1,2] exposure for removal of solder paste volatiles and activation of the fluxes, where the flux components begin oxide reduction on component and pads. However, long soak times will dry up the flux. A minimized soaking zone reduces voiding, poor wetting, solder balling, and solder joint opens.

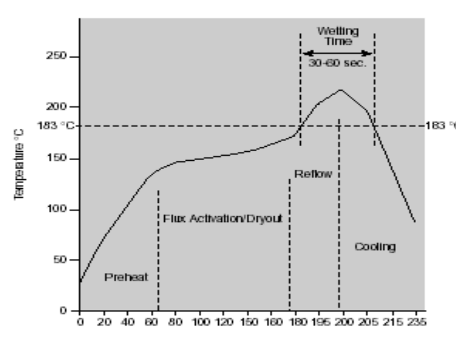


Fig. 1 Typical Reflow profile parameter for Sn/Pb

The RTP profile has several advantages over the RSP reflow profile. The RTP profile generally will result in brighter and shinier joints and fewer problems concerning solder ability, since the solder paste reflow in a RTP profile will still contain its flux vehicle throughout the entirety of the preheat stage. This also will promote better wetting, and thus the RSP should be used on difficult-to-wet alloys and parts. In addition, the RSP profile is more economical due to the reduced heating energy used in the first half of the oven. Furthermore, troubleshooting the RTP tends to be a relatively simple process, and operators with experience troubleshooting the RSP profile should have no difficulty in adjusting the RTS profile in order to achieve optimum profiling results [2].

2.0 MATERIALS AND METHODS

2.1 Ball attach process

Fig. shows the summary of the process flow for overall experiment. The preparation of the test coupons was initiated by applying flux on the solder pad. For applying flux and placement of the solder balls, two stencils that are flux stencil and ball placement stencil were chosen. The flux stencil was aligned with substrate pad. Flux was brushed across the stencil apertures. Flux was then deposited on the substrate pad. To cleaning the pad surface, the flux holds the solder balls in place until they are reflowed. The test vehicle was then aligned to match the aperture openings of the ball placement stencil. The solder ball was brushed across the stencil openings. In certain cases, causing solder ball to stick to the stencil aperture, thus resulting missing balls. The stencil was the removed, leaving the solder balls on the substrate pad. The missing ball was manually placed. The test coupon was then reflowed whereupon the solder balls formed bumps. During reflow, the ball self centered on the substratepad[3].

In this study, lead-free solder balls with composition; Sn: 95.5%, Ag:3.8%, Cu:0.7% Ni/Au Surface finish using two different reflow profiles-temperature versus time were used (Fig. 1 & 2). The reflow was conducted in a seven forced convection oven, at a peak reflow temperature of 245±5°C with optimized soak time under 130°C-170°C. The reflow was conducted in a seven zone forced convention oven

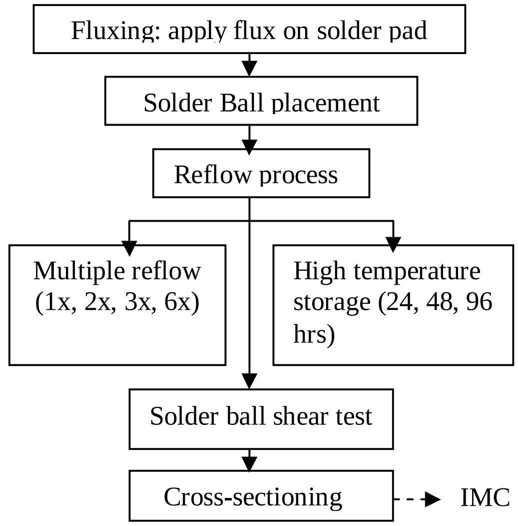
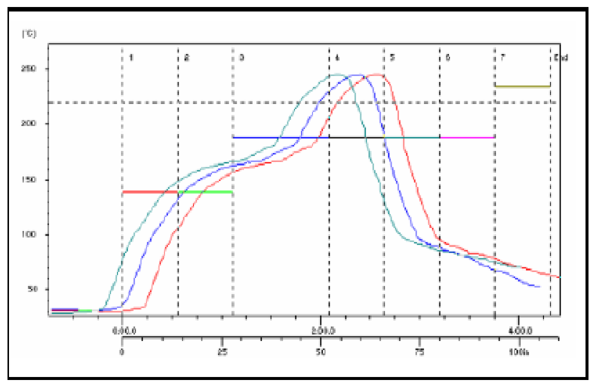
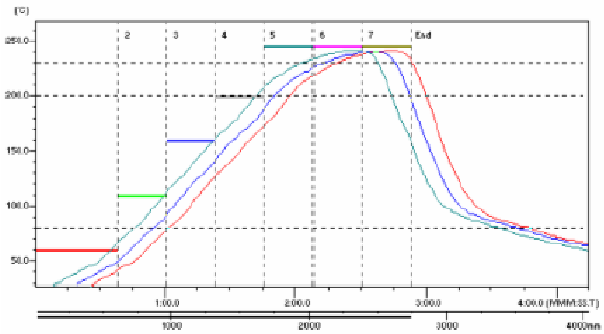


Fig 2 Experimental flow diagram



Current Profile Parameters	Current Spec	Actual		
		Rear TC	Center TC	Front TC
Ramp Rate (50 to 150°C)	<3°C/sec	2.41	2.41	2.38
Peak Temp	240 to 260°C	245.5	245.5	246
Dwell Time > 220°C	30 to 60 sec	35.5	35	34.5
Cooling Rate (240 to 210°C)	<6°C/sec	2.55	2.67	2.46
Additional Info :	Rec. Spec			
Soak Time btw 130 to 170 deg.C	max 90 sec	55	56	56
Dwell Time > 230°C (liquidus temp @229)	30 to 40 sec	30	30	29

Fig. 3 RSP profiles



Recommended Profile Parameters	Recommended Spec	Actual		
		Rear TC	Center TC	Front TC
Ramp Rate (80 to 200°C)	<5°C/sec	2.16	2.16	2.14
Peak Temp	235 to 250°C	240.5	240	241
Dwell Time > 220°C (liquidus temp @229	40 to 50 sec	49	50	49
Cooling Rate (240 to 210°C)	<6°C/sec	2.55	2.67	2.46
Additional Info :	Recommended Spec			
Soak Time btw 130 to 170 deg.C	max 90 sec	21	19	20
Dwell Time > 230°C (liquidus temp @229	30 to 40 sec	34.5	33	33.5

Fig. 4 RTP profiles

Test coupon (refer Table 2.2) were performed preconditioning prior to reliability test, multiple reflow operations under 1, 2, 3 and 6 times cycling at 260°C with accordance to JESD22-A113 [4]. Also, the unit were dry bake in a HTS oven for different storage time between 24, 48 and 96 hours at 150°C. HTS is used to determine the effect of temperature and time under storage condition at elevated temperatures without electrical stress applied,JESD22-A103B[5]. Ball shear test were performed with sheared off solder ball from inner and outer rows using *DAGE 2400 series* shear machine, JESD22-B117[6]. For intermetallic thickness and area measurement, the units were cross-sectioned and polished for better observation and examination under Microscope and Image Analyzer. Elemental analysis was done using EDX.

Table 1 Package information

Package type	Tape ball grid arrays (TBGA)
Package size	0.76 mm ball diameter (30 mils), 1.27 mm pitch, 37.5 x 37.5 pkg size
Solder ball composition	Sn: 95.5%, Ag: 3.8%, Cu:0.7%

Table 2 Test coupon

Condition	Sample size
SBS (T0 & after test)	10 units/lot, 8 balls/unit
Multiple reflow (1x,2x,3x,6x) -SBS -Cross-section	 5 units/lot/readpnt 8 balls/unit 3 units/lot/readpnt 2 balls/unit
High Temperature storage test (24,48,96 hrs) -SBS -Cross-section	 5 units/lot/readpnt 8 balls/unit 3 units/lot/readpnt 2 balls/unit

2.2 Solder ball shear test (SBS)

Ball shear test is a destructive method to determine the ability of BGA solders balls to withstand mechanical shear forces.

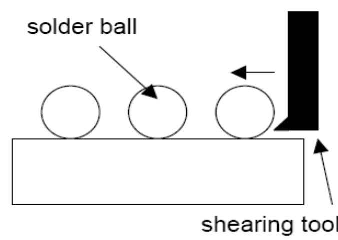


Fig. 5 Shear test diagram

The shearing tool was aligned to the ball in the conventional manner as shown in Fig. 2.3.Initiate the test; (a) complete a normal land (b) complete a step-back to the programmed shear height. The sample was then moving away from the tool to create the acceleration distance. From this position, the sample is accelerated to the programmed test speed and the ball contacts the tool. Having a region of constant velocity (acceleration distance), the speed is held prior to and during impact with the ball. Lastly, the sample was decelerated to complete the test. The location of the balls to be tested in TBGA is shown in Fig. 6, where four balls were randomly selected from outer location and four balls from inner location. Each ball has 30 mils diameter size and the tester has been set-up with 300 mm/s for shear speed and 40 cm for ball shear height from the substrate.

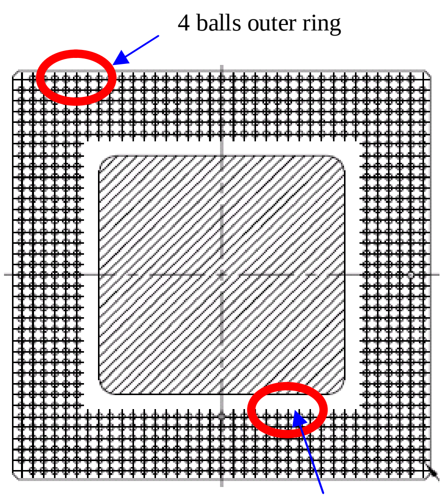


Fig. 6 TBGA unit schematic diagram

3.0 RESULTS AND DISCUSSIONS

3.1 Solderball shear strength and IMC thickness

3.1.1 As reflow (T0) and after test

Table 3 shows the effect of reflow profile towards shear strength of solder joint before and after ball shear test. As reflow, RTP samples shows highest average strength and indicates significant differences compared to RSP samples. When subjected to test, it is shows the decreasing of strength of all samples. But RTP samples show highest average strength with lowest Std. Deviation.

Table 3 Shear strength of samples as reflow and after test

	As reflow (T0)		After test	
	Average	Std.Dev	Average	Std.Dev
RSP1	1680	123.29	1581	111.87
RSP2	1625	119.24	1550	112.38
RSP3	1695	130.36	1581	107.45
RTP	1728	107.49	1593	97.18

**Remark: all units in grams*

3.1.2 After multiple reflows

Fig. 7 shows that RSP samples presented the increasing of strength up to 3x reflow before sharply decreased when extended to 6x reflow. This is consistent with [7] that reported 3x reflow produces >40% increase in solder ball strength over received condition due to micro refining during resolidification. Instead of RTP that begin to decrease when extended to 3x reflow.

Referred to Fig. 8, RTP samples show optimal IMC thickness (<2.50 μm) as reflow cycles increased. RSP samples show the rapid growth of IMC thickness that lead to weaken the solder joint. Low shear force and strength will identify a weak solder joint, a high shear strength may be observed on packages which exhibits non-robust behavior in subsequent reliability testing as well as in the field [8].

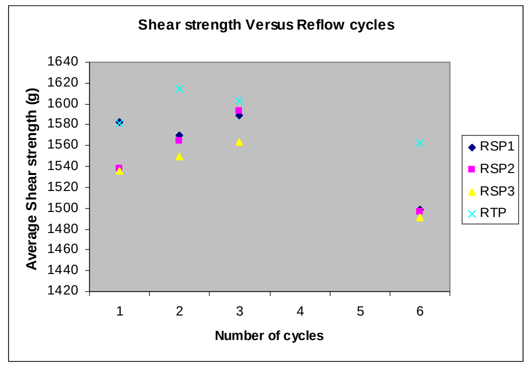


Fig. 7 Shear strength versus reflow cycles graph

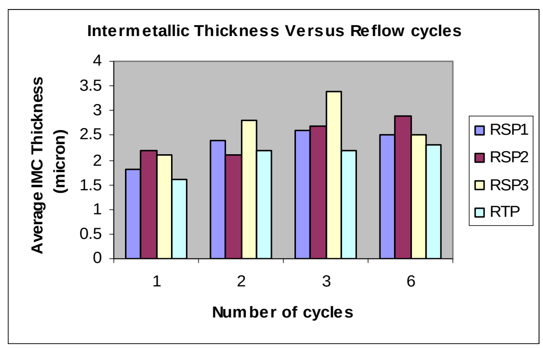


Fig. 8 IMC thickness versus reflow cycles graph

3.1.3 After high temperature storage test

The effect of high temperature storage upon shear strength is shown in Fig. 9. It is indicated the decreasing of shear strength as storage time increased. As depicted in Fig. 10, the result shows how IMC thickness is proportional to longer storage times. From both figures, it also exhibited that RTP samples gives better strength and thinner IMC than RSP samples. Each unit show ductile failure means deformation energy is large.

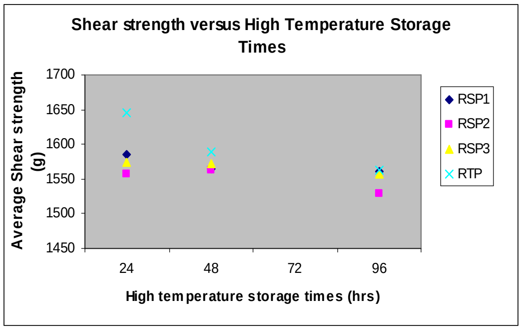


Fig. 9 Shear strength versus reflow cycles graph

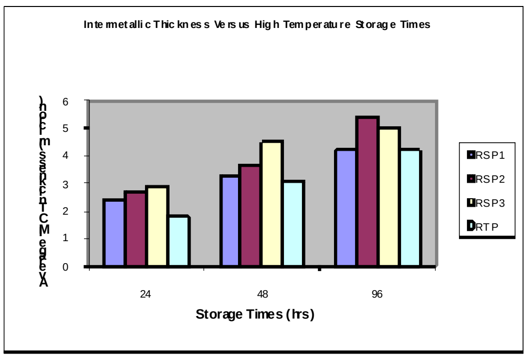


Fig. 10 IMC thickness versus reflow cycles graph

3.2 Elemental analysis of IMC (SEM-EDX)

In Cu-contained solders such as SnAgCu, ternary IMCs that consist of Cu, Ni and Sn, were observed [9]. EDX results (Fig.12) used to measure %weight of Cu, Ag, Sn, Ni element presented in IMC solder joint, localized on 1 (peak) & 2 (interface) position as shown in Fig. 11 below. Hence the IMC phase distribution can be determined.

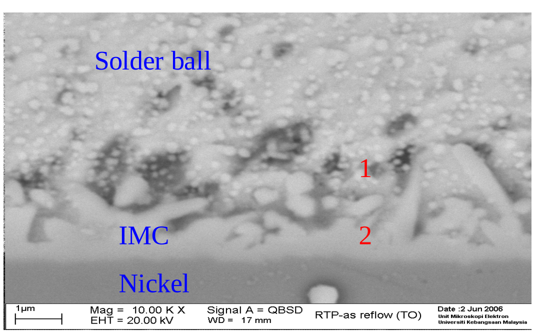


Fig. 11 SEM pictures on IMC

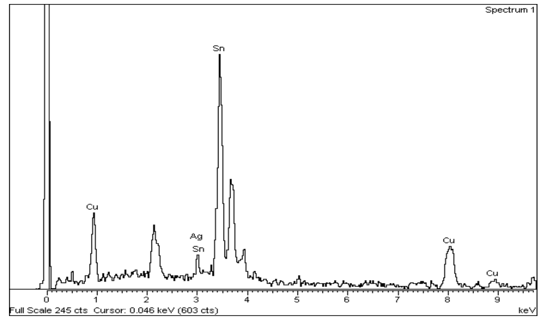


Fig. 12 EDX results

In SAC systems, $(Cu,Ni)_6Sn_5$ IMC firstly formed and $(Ni,Cu)_3Sn_4$ IMC followed [9]. It is agreed from Table 4, the formation of Cu-Sn or Cu-Ni-Sn intermetallic phases present. Weight percentage of Nickel is much higher at IMC interface than peak. Presenting of little Ag weight% does not give significant effect on IMC formation and microstructure. For RTP samples %Sn at peak decreased with increasing reflow cycle but RSP samples differs. Contradict with %Cu that is remaining increase for RTP samples.

5.0 CONCLUSION

From study on Sn3.8Ag0.7Cu, it can be summarized that:

- In term of reflow profile, RTP shows better results than RSP according to shear strength as reflow (T0), multiple reflow and high temperature storage test. RTP profile gives better flux activation and wetting action that enables more reliable and stronger solder joint.
- It is consistent with IMC thickness that thicken when storage time and reflow cycle increased.
- Elemental analysis by EDAX shows Cu-Sn IMC phase at the peak and Ni-Sn-Cu phase presented at interface position.

Table 4 Sn3.8Ag0.7Cu EDX results

I. RSP						
Element	As reflow (T0)		1x		6x	
	1	2	1	2	1	2
Cu	48.91	42.84	37.47	35.73	28.82	26.69
Ag	5.99	-	3.25	2.16	5.68	-
Sn	42.18	46.79	56.08	53.12	61.20	53.40
Ni	2.92	10.37	3.19	9.00	4.29	19.90
II. RTP						
	As reflow (T0)		1x		6x	
	1	2	1	2	1	2
Cu	24.36	28.12	39.34	32.33	43.97	43.85
Ag	4.86	-	-	-	2.60	-
Sn	70.38	53.04	56.62	8.62	49.48	48.03
Ni	-	18.85	4.04	59.04	3.96	8.13

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