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# Rheological Behaviors and Their Correlation with Printing Performance of Silver Paste for LTCC Tape

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## 1. Introduction

Low Temperature Co-fired Ceramic (LTCC) technology has attracted much attention for high frequency applications due to the advantages in preparing 3D circuits within a ceramic block that enables burying of passive elements; resistor, inductor and capacitor (Jantunen et al., 2003). This technology also offers another advantages such as low fabrication cost due to parallel process, utilizing high conducting metal, higher interconnect density, high performance thermal management system, shrinking of circuit dimensions and high level of passive integration (Lin and Jean, 2004; Gao et al., 2010). The LTCC multilayer technology process generally consists of cutting the green tape ceramic into the required dimension, via punching, via filling, screen printing, stacking, lamination and co-firing process. All these steps are important to achieve a good quality of the final structure. Furthermore, LTCC technology requires cofiring process of conductor and ceramic-glass substrate. The co-firing mismatch should be avoided to make sure the resulting product has good appearance. The key point of LTCC technology is the screen printing process of thick-film technology which strongly depends on the optimization of the conductor paste rheological behavior. Besides, the characteristics and the quality of printed conductor lines are greatly affected by some process variables such as screen printing speed, angle and geometry of the squeegee, snap-off and screen mesh parameter including the paste characteristics (Hornstra et al., 1997; Yin et al., 2008). The performance of the paste depends on the variety of factors including storage, how easily and accurately it can be deposited (printing) and the flow characteristics (rheology) (Nguty and Ekere, 2000). Thick-film paste must maintain good printability throughout the time on the screen and the screen parameters must allow for high throughput and repeatability results (Harper, 2001; Buzby & Donie, 2008). The successful story of making multilayer substrate is depends on this steps. Consequently, a thorough understanding of the influence of the paste rheological behavior and the combination with other parameters is essential if this objective is to be met.

Generally, the electrical connection between components and layers are given by the conductor paste such as silver, copper, gold, silver-palladium, silver-platinum and etc. Compared to the other conductor materials, silver thick film has been used as the main conductive material for LTCC technology due to their excellent electrical properties, thermal

conductivity and the lower cost price of conductor material (Wu et al., 2010; Chen et al., 2010). The characteristics of the silver particles strongly affect the paste rheology and subsequently alter the densification of the printed track. Different formulations of the paste are used to produce conductors that basically consists of several major ingredients; (1) the metal powders, which provide the conductive phase; (2) glasses or oxides, which act as a permanent binder and also promote sintering of metal powders during firing and enable binding of the functional film to the substrate; (3) organic vehicle, which disperse the functional and binder components to impart the desired rheological properties to the paste; and (4) a solvent or thinner that establishes the viscosity of the vehicle phase (Taylor et al., 1981; Lin and Wang, 1996; Rane et al., 2004; Sergent, 2007). Such pastes are screen printed in the desired pattern on the substrate, dried and fired at a certain temperatures to form a conducting thick-film with a thickness ranging from 3 to 30  $\mu\text{m}$  (Rane et al., 2003).

### 1.1 Basic information/thick-film materials

Thick-film is generally considered to consist of layers of paste deposited onto the substrate. One of the key factors that distinguish thick-film circuit is a method of thick film deposition.

In LTCC process, screen printing is one of the most dominant methods to deposit conductor paste on a substrate. The screen printing of thick film patterns on the LTCC multilayer substrate is employed for thick film systems due to a low-cost and much simpler process to produce a circuit design on substrate compared to other process. The printing process are done only at the place where required and follow the design pattern which are prepared earlier (Vasudivan & Zhiping, 2010). The printing quality and the fine line printing resolution patterns is necessary in order to achieve high component density and high frequency applications (Dubey, 1975; Kim et al., 2010). Successful transferred pattern onto the substrate depends on the rheology of the paste material. The range of most available for thick-film technology is determined by their capacity to be both printed and fired. Establish thick-film technology is based on three classes of material supplies in the form of printing paste; conductors, resistors and dielectrics. For this report we only concentrate on the conductor paste.

Thick-film circuits are created in thick-film printing patterns in paste which basically composed of organic carrier, glass-frit and active elements such as gold, silver, silver platinum and silver palladium. As mention above, silver paste is the most selected material due to the good conductivity and good characteristics which depends on the functional paste whether precious metal such silver, gold or base metal such Ni, Cr and Al. An organic carrier dispersed the binder and functional components to impart the desired rheological properties of the paste while the glass-frit act as permanent binder and help to promote metal powders during sintering and also provide binding between thick-film and the substrate (Hwang et al., 2009; Shiyong et al., 2008). The printing process is known to be controlled by a number of process parameters such as screen mesh parameters, printer setting parameters, environmental conditions and paste parameters (Durairaj et al., 2009b). Some of these parameters are fixed (eg. screen mesh). However the paste parameters generally change during the printing process cycles; before printing process, during printing and after printing process as seen in Fig. 1. So, it also noted that the viscosity is a function of the time. One of the paste parameters is the rheological properties and flow history of the

paste (Parikh et al., 1991; Burnside et al., 2000). The printing behavior of the paste is characterized by its rheology through the viscosity value.

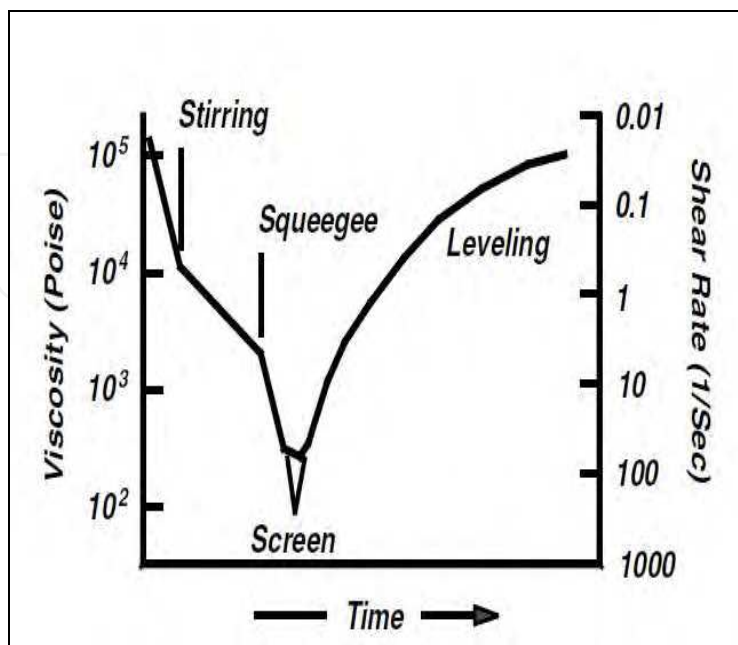


Fig. 1. Variation in the paste viscosity at different stages of the printing cycle (Barlow & Elshabini, 2007)

The viscosity is the most important rheological characteristics of the conducting paste (Gilleo, 1989). The conducting paste for screen printing process should show the pseudoplastic behavior which displays a decreasing viscosity with an increasing shear rate (Hoorstra et al., 1997). However, to be suitable for screen printing, conducting paste should be somewhat thixotropic in nature. A thixotropic fluid is one in which the shear rate/shear stress ratio is nonlinear. As the shear rate (which translates to the combination of squeegee pressure, velocity, and screen tension) is increased, the paste becomes substantially thinner, causing it to flow more readily.

The optimum operating viscosity of the paste is dependent on the parameters with the screen printing process. The variations in squeegee speed, squeegee to screen angle, squeegee pressure and snap-off distances will affect the quality of the printed film. If the printed lines have a tendency to spread on standing, it is likely that the viscosity of the paste is too low. Chiu, (2003) in his experiment also noted that the paste viscosity is a significant factor to control the line width including the thickness and roughness of the printed pattern. The paste viscosity is too high if the printed films display mesh marking, pinholes or very thin areas covered with paste.

The aim of this work is to modify the viscosity of silver paste in order to get the required thickness and fine line printing of printed material on the substrate. As well known, controlling the properties of resulting conductor thick film paste is not a simple task, so in order to comply with required properties, the conductor paste need to do some adjustment in terms of its viscosity behavior. Viscosity can be lowered (by addition of the solvent) or increased (by addition of a thixotropic nonvolatile vehicle), although the latter will require re-milling of the paste.

The investigation of rheology of the paste has been studied by several researchers especially for solder paste and conductor material for solar cell applications such as Shiyong et al., (2008), Amalu et al., (2011), Mallik et al., (2009), Durairaj et al., (2004), and Burnside et al., (2000). Their studies reported that the solder paste shows thixotropics behavior, shear thinning and yield stress. Jackson et al., (2002) noted in their paper, a good quality paste will have optimum shear thinning properties allowing flow in mesh aperture, a suitable thixotropic nature for recovery and a non tendency to slump after printing. The paste also should retain its intended printed thickness and continuity. Previous studies by Evans and Beddow, (1987) found that viscosity of solder paste increase with increasing the metal content and decrease with increase particle size distribution and temperature. However, not much literature has been found for the study of modification of wt% of thinner in order to adjust the viscosity of the paste suitable for screen printing process. The work in this study was divided into several parts; part 1 is the sample preparation of different wt% of thinner. In this part the viscosity measurement is using the Brookfield viscometer model RV-DV cone and plate with CP-52 spindle. At the same time part 2 is done; preparation of LTCC tape for the whole multilayer substrate process. The results for the part 1 will be used for part 2. After finish part 2, characterization of part 3 will be carry out. Sample analysis and detail discussion is carried out to explain the research findings.

## 2. Methodology

In the following sections, the various process stages will be described. The factors that have the most influence on the quality of the line resolution is the viscosity of the paste.

### 2.1 Sample preparation

Seven samples with different viscosities of the silver paste were used in this process. In this work, a thinner that contains texanol is used to modify the viscosity of commercial LTCC silver paste. The addition of thinner used is varies by its weight percentage from 2, 4, 6, 8, 10 to 12% of 4g silver paste. Table 1 shows a sample description that going to be used for further discussion.

Sample labels	S1	S2	S3	S4	S5	S6	S7
Weight % of Thinner	0	2	4	6	8	10	12

Table 1. Samples descriptions of silver conductor paste with varies thinner wt%.

### 2.2 Viscosity measurement

There is some equipment to be used for viscosity measurement which broadly classified into two categories; dynamic and kinematic viscometer. A dynamic viscometer is one of the shear rate can be controlled and measured (rotational viscometer). It is the only type of viscosity measurement that is relevant to fluids where the viscosity is related to the shear rate (non-Newtonian fluids). A kinematic viscometer is where the shear rate can neither be controlled nor measured, for example capillary viscometer.

For the purpose of this research, brief information about cone and plate geometry viscometer will be given. As noted in Brookfield catalog, cone and plate viscometer offers absolute viscosity determination with precise shear rate and shear stress information. The sample volume is extremely small amount and temperature controlled is easily accomplished. Cone and plate geometry viscometer is particularly advanced rheological analysis of non-Newtonian fluids (Phair & Kaiser, 2009).

The viscosity measurement was carried out in semi-clean room condition and the ambient temperature is maintained at 25°C. This is the key factor which might be affects the printing quality. Brookfield viscometer Model RV-DV cone & plate geometry with CP-52 spindle, using a plate 1.2 cm radius and a cone angle of 3 ° is used. Viscometer speed was set at 0.5, 1.0, 1.5, 2.0 and 2.5 RPM. The viscosity and torque readings were recorded. Viscosity of the paste for the sample 2, 4, 6, 8, 10 and 12 wt% of thinner was achieved from the measurement.

### 2.3 Multilayer substrate process

The quality and performance of the paste was evaluated by the screen printing process where the standard thickness is about 15-21  $\mu\text{m}$ . Screen printing process was carried out for Heraeus tape HL2000 on a KEKO P-200Avf Screen Printer Machine using the TC0306 silver conductor paste from Heraeus. Heraeus HL2000 LTCC is an alumina-based ceramic glass system that has an excellent dielectric properties; the dielectric constant is  $7.3 \pm 0.3$  and dielectric loss ( $\tan \delta$ ) is about 0.0026. The process was started by printing the test pattern design on the standard LTCC tape dimension 21.4 cm x 21.4 cm.

Printing parameters	Value
Squeegee pressure	0.1 MPa
Squeegee speed	100 mm/s
Snap-off	1.0 mm

Table 2. Printing parameters for printing process of Heraeus HL2000 LTCC tape.

The printing process was also done in a temperature controlled room at 25 °C and using a standard 325 mesh and angle of 22.5°. The printing parameter used for the process were fixed and controlled to eliminate the variation from the printer (London, 2008). Printing parameter used for the printing process is shown in Table 2.

After the printing, the substrate was dried at 80°C for about 20 minutes to remove portion of volatile organic solvent before manual stacking process (see Fig. 2) was carried out to stack the printed tape with 8 “dummy” layers. Drying of the solvents of the conductive paste will reduce the wet thickness volume about 50%. The whole substrate was then laminate using isostatic lamination system ILS-6A at 75°C with pressure of 1500 psi (10MPa) for 10 minutes. The laminated samples were then fired up to 850°C by using an LTCC firing profile as suggested by a tape manufacturer.

The effect of the screen printing line resolution was assessed by printing a test pattern design as seen in Fig. 3. The unfired and fired samples were then measured for the line width resolution using an optical microscope OLYMPUS MX40. The line resolution is observed for the horizontal and vertical line.

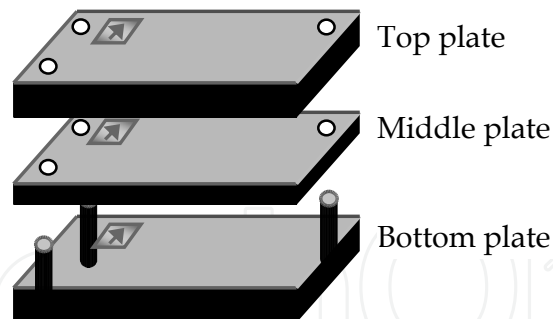


Fig. 2. The manual stacker for collating and stacking process (Alias et al., 2010)

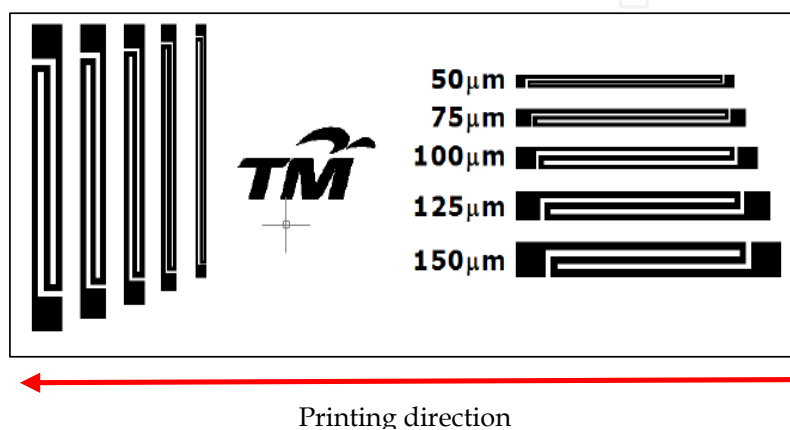


Fig. 3. Printing pattern for the line width evaluation

## 2.3 Analysis and measurement

### 2.3.1 Shrinkage and density measurement

The shrinkage of the Heraeus tape is generally calculated based on equation 1.

$$\text{Shrinkage} = \left( \frac{\text{Length}_{\text{before fired}} - \text{Length}_{\text{after fired}}}{\text{Length}_{\text{before fired}}} \right) \times 100\% \quad (1)$$

The properties of the final ceramic composite materials depend on the sintered density of the whole substrate. A stacked and laminated LTCC substrate before firing consists of a relatively porous compact of oxides in combination with a polymer solvent. During sintering the organic solvent evaporates and the oxides react to form crystallites, or grains of the required composition, the grains nucleating at discrete centers and growing outwards until the boundaries meet those of the neighboring crystallites. During this process, the density of the material rises; if this process were to yield perfect crystals meeting at perfect boundaries the density would rise to the theoretical maximum, i.e. the x-ray density, which is the material mass in a perfect unit crystal cell divided by the cell volume. In practice imperfections occur and the sintered mass has microscopic voids both within the grains and at the grain boundaries. The resulting density is referred to as the sintered density. The density of the sample was measured using the Archimedes principle shown in equation (2);

$$\rho = \left( \frac{W_a}{W_w} \right) \rho^*_{*w} \quad (2)$$

where  $W_a$  = weight of sample in air

$W_w$  = weight of sample in water

$\rho^*_{*w}$  = density of water = 1 gcm<sup>-3</sup>

### 2.3.2 Monitoring film thickness

Film thickness need to be carefully controlled and monitored. It is desirable to measure the film thickness at an early stage in the thick film process to reduce error in determination of film thickness for design requirements. For this reason, the thickness of the film should be measured before and after fired. There are some methods to determine the metal thickness using surfometer and non-destructive method. However, in this work we used SEM through cross-section view to measure the film thickness using a FEI NOVA Nano SEM 400 machine. Most of the samples were imaged several times, with at least three pictures in each case, from different areas of the sample holder.

## 3. Results and discussion

### 3.1 Viscosity analysis

The viscosity of thick-film paste is tailored to meet some requirement for screen printing process such as; 1) thixotropic behavior, 2) must have yield point and should have some degrees of hysteresis i.e; the viscosity should be higher with decreasing pressure, as the paste will be on the substrate on the time. Table 3 shows the viscosity for the entire sample for up-curve and down-curve measurement. The paste generally exhibits good shear thinning with a range of viscosity about 7000 to 65000 poise observed at various wt% of thinner. As seen in the Hereaus data sheet, suitable viscosity value for screen printing process is in the range of 2000-3000 poise.

Fig. 4 shows the variation of viscosity and shear rate of silver paste with different percentage of thinner. As we can see the trend exhibited by all the samples is generally similar to the work carried out by Bell et al., (1987) and Morissette et al., (2001) on the influence of paste rheology on print morphology and component properties. Sample 0% to 6% thinner the viscosity slightly shows decreasing trend. It also obvious that for sample 0-4wt % the trend is slightly overlapped for higher shear rate started from 3.00 to 5.00.

However, the viscosity measured for sample with higher percentage of thinner of 8%, 10% and 12% did not shows a significant change which could be due to the generation of a liquid-rich layer at the interface between the sample and cone and plate geometry causing a lower viscosity (Duraiaraj et al., 2009a).

Rheological characterization of the paste is to measure the relationship between shear stress and shear rate varying harmonically with the time, indicating the level of interparticle force or flocculation in the paste. The ideal paste for thick-film films should have a proper degree of pseudoplastic as well as thixotropic behavior (Wu et al., 2010). The thixotropic effect is a result of aggregation of suspended particles. Aggregation in the system caused by the attraction forces such as Van der Waals and repulsion forces due to steric and electrostatic



effect on the particles. This force prevents the particles from approaching close to each other and create weak physical bond. When the suspension is sheared, this weak force are broken causing the network to break down. A paste with the excellent thixotropic could produce a good printability, help to avoid failure such as incomplete line resolution (Wu et al., 2011; Neidert et al., 2008).

Up curve	Speed (RPM)	0% thinner	2% thinner	4% thinner	6% thinner	8% thinner	10% thinner	12% thinner
	0.5	65882	64096	58540	44054	25996	21035	10716
	1	54670	52884	50801	37505	22622	17862	8938
	1.5	47758	47229	45707	34925	21101	16801	7608
	2	42962	42962	42069	32842	20042	15925	7393
	2.5	39331	39291	39251	30996	19288	15399	7174
Down curve	Speed (RPM)	0% thinner	2% thinner	4% thinner	6% thinner	8% thinner	10% thinner	12% thinner
	2.5	39609	39331	39490	31750	19526	15518	7342
	2	42863	42466	42218	33536	20489	16123	7640
	1.5	47559	46369	45906	35984	21696	17000	8004
	1	54869	52289	50999	39192	23614	18157	8434
	0.5	68660	61913	60326	45244	26988	20241	9327

Table 3. Viscosity of silver paste with varies thinner weight percentage (in Poise unit)

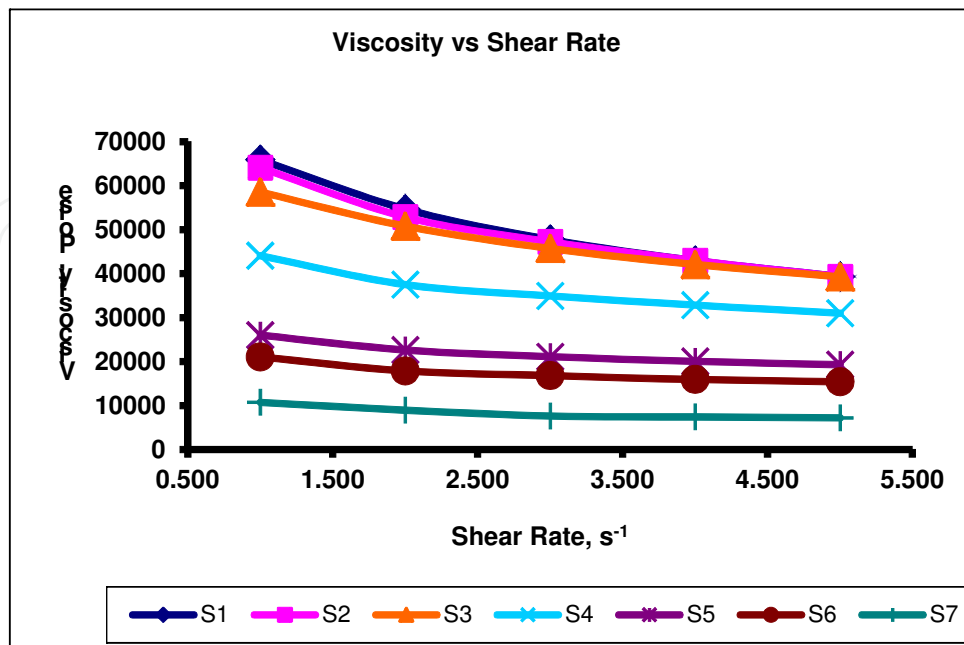


Fig. 4. Viscosity vs. shear rate of silver paste with varies weight% thinner

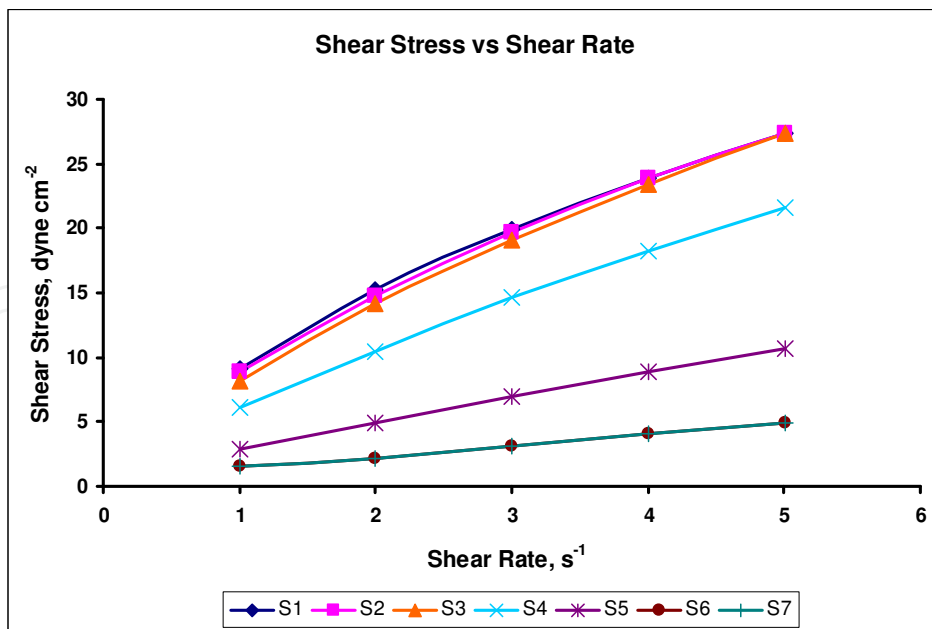


Fig. 5. Shear stress vs shear rate of silver with varies wt% of thinner

Fig. 5 shows the relation of shear stress and shear rate of silver paste with different wt % of thinner. The trend of non-Newtonian behavior is consistent with the results found by Chhabra & Richardson, (1999) for the types of time-independent flow behavior. The time-independent non-Newtonian fluid behavior observed is pseudoplasticity or shear-thinning characterized by an apparent viscosity which decreases with increasing shear rate. Evidently, these suspensions exhibit both shear-thinning and shear thickening behavior over different range of shear rate and different wt% of thinner. The viscosity and shear stress relationship with increasing percentage of thinner is plotted in Fig 6. It is clearly observed that both viscosity and shear stress decreases respectively.

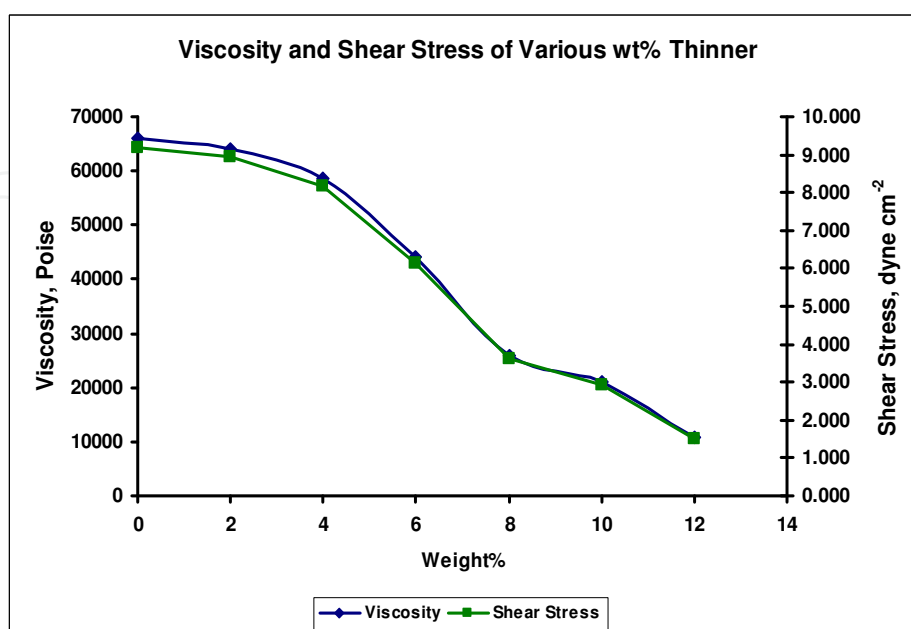


Fig. 6. Viscosity and shear stress of silver paste with varies wt% of thinner

### 3.2 Effects of weight percentage thinner on the line width resolution

The relationship of the line width resolution before firing process and after firing process and wt% of thinner is plotted in Fig. 7. The variation of the line width for 100  $\mu\text{m}$  line resolution were found to fluctuate with increasing the wt% of thinner meaning that it did not shows a significant trend of the line width with increasing the wt % of thinner. However, due to the optimization of rheology behavior of sample S3 similar to the viscosity of the commercial pastes in the Hereaus data sheets (Hereaus design guideline) so the line width resolution using 4% thinner (S3) is acceptable compared to the rest wt % of thinner and it can be used for the printing process.

Fig. 8 shows the relationship between viscosity and shear stress with shear rate of sample S3. As we can see, the viscosity decrease and the shear stress increase as the shear rate increases. The relation of shear rate and shear stress shows that the paste has thixotropic behavior. The plot is similar to the graph by Chhabra & Richardson, (2008). Through this plot, we can see that not only the values of viscosity are seen to be different but the rate of decrease viscosity with shear rate is also seen to be varied. When shear stress increases the viscosity of the paste with good rheology decrease sharply, paste can flow rapidly through screen (Wang et al., 2002). The similar behavior of this modification paste (S3) with the commercial paste made this sample might be able to be used for fabrication of electrical connection using screen printing process.

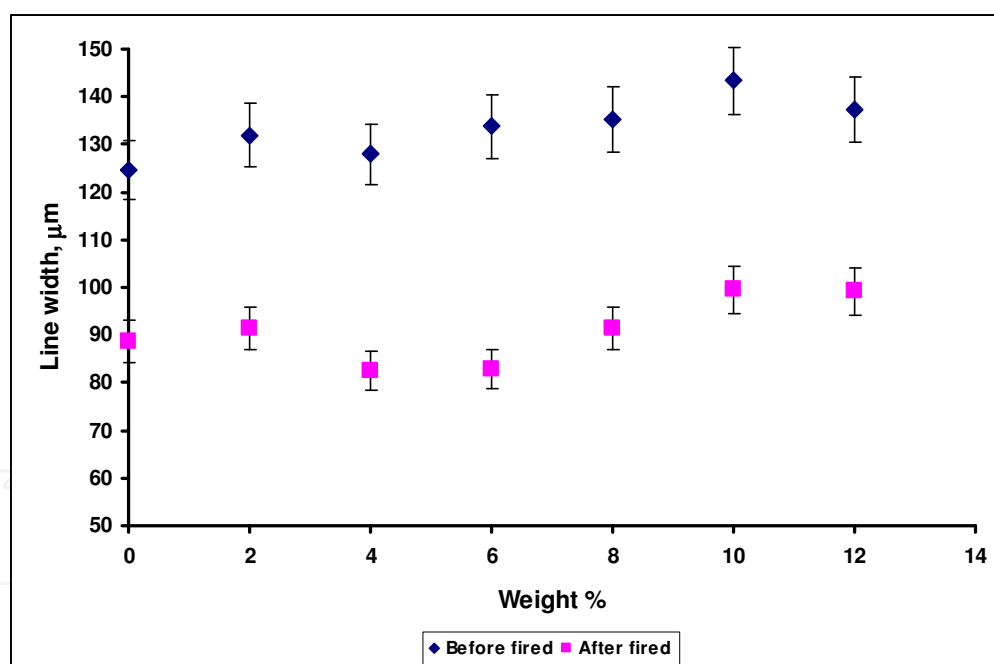


Fig. 7. Printing line width (before and after fired) of silver paste with varies wt% of thinner

The relation of printed thickness and z-shrinkage with the percentage of thinner is presented in Fig. 9. The thickness of the fired film is about 4  $\mu\text{m}$  to 33  $\mu\text{m}$  determined via cross section observation using SEM. It is clearly observed that increasing percentage of thinner will cause the printed thickness of the metal conductor on the substrate shows decreasing trend. When the thinner content increase in the paste the viscosity decrease and the films become thinner. It is consistent with the results found by Jabbour et al., (2001),

where the thickness of the printed pattern depends on the viscosity of the paste. On the other hand, the linear shrinkage for the whole substrate did not show significant increase with increase wt % of thinner. This shrinkage can be attributed to the solvent loss. Theoretically, the thickness of metal conductor should be constant regardless of the line width since the same mesh is used (Shin et al., 2009). It could be attributed this result to the fact that the edges of the printed line should have a moderate thickness to result in uniform and continuous line width.

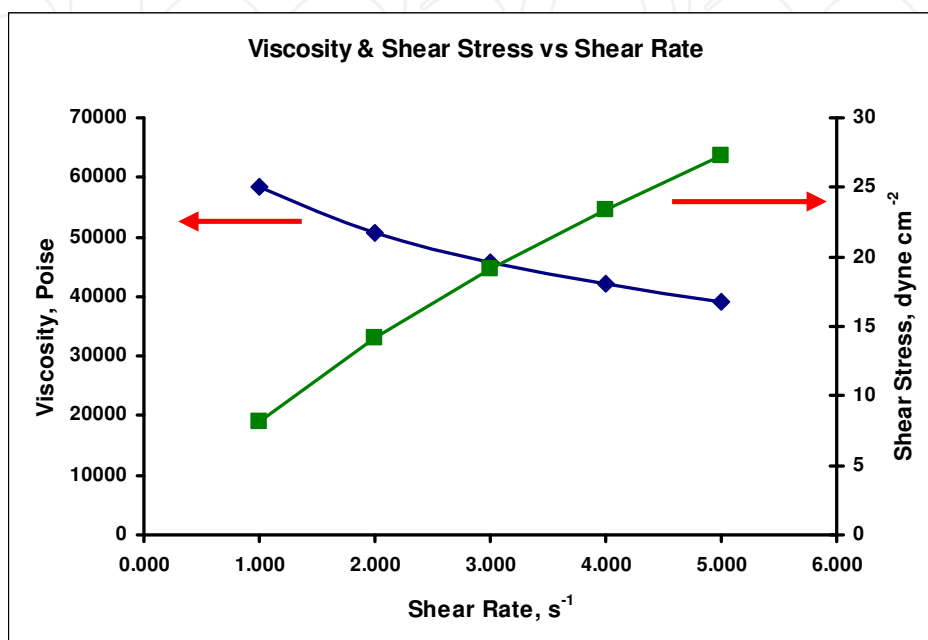


Fig. 8. Viscosity and shear stress as a function of shear rate for silver paste with 4 wt% of thinner (sample S3)

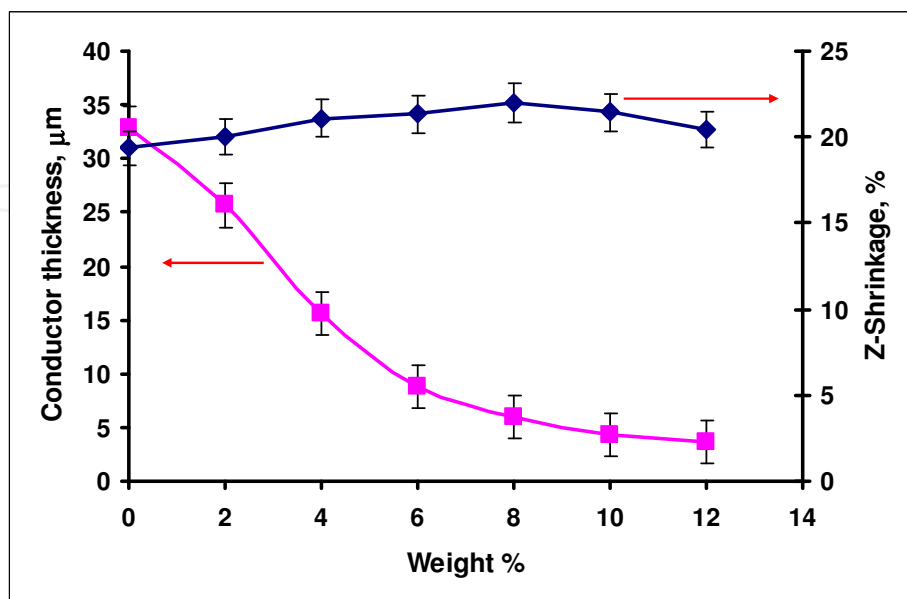


Fig. 9. Influence of printed thickness and shrinkage of silver paste with varies wt% of thinner

### 3.3 Printing results - Line resolution

A series of commercial pastes have been tested for the ability to easily print for various line width and spacing which designed for the horizontal and vertical line at different widths that are 50  $\mu\text{m}$ , 75  $\mu\text{m}$ , 100  $\mu\text{m}$  and 125  $\mu\text{m}$ . The different line width resolution was observed under optical microscope and was found that for sample with zero percentage of thinner (no thinner), the saw-tooth-edge line was observed as shown in Fig. 10. The line resolution is evaluated from the incomplete line and complete line for the required line width. Lines are incomplete and a portion of the lines is missing. The amount of silver seems to be insufficient to form continuous lines. It can be noted here that at lower silver content the edges of the printed lines look spread out with the paste due to its lower viscosity. This might be due to the results of insufficient adhesion of the lines to the LTCC tape. In other way, the line is broken could also be due to the mesh problem. For this study, the screen mesh 325 with the angle of 22.5° is used. The mesh opening and the viscosity of the paste is not compatible i.e; ink cannot pass through the mesh openings/mesh is unclean. As noted by Pudas et al., (2004) incomplete transfer pattern means the high variations in the printed results.

If it is broken line, then it shows that there are some problems regarding screen printing process (Shapee et al., 2010). It is defined has open defects that are voids on the conductor extending across more than 80% of the conductor width (Webster, 1975). Print poor resolution means that the printed film does not match the layout in terms of dimensions or shape. It may because of improper rheology or a flaw in the screen (Sergent, 2007). It is obvious that the rheology of the paste is the main factor that affects the poor print resolution. Higher viscosity is better for the good print resolution. The line is considered has a good connectivity when it is no broken line along the line. It also shows that the line resolution for the vertical direction is better than the horizontal direction. Producing optimal screen printed patterns involves consideration of many factors including printer setting, screen options, substrate preparation and paste rheology (Cao et al., 2006). Interaction between these factors must be considered (Dollen & Barnett, 2005).

If the printed pattern is too thick, the thinner should be added to the paste to adjust the rheology of the paste. As mention by Barlow & Elshabini, (2007), the thinner is useful to modify the thicker printing provided by the organic binder. The thinner can integrate together with the binder to improve paste characteristics and printing performance. The influence of paste rheology on the line resolution of as printed material has been investigated previously by Wang & Dougherty, (1994) and Vasudivan & Zhipping, (2010). As noted by Schwanke & Polhner, (2008) in their work of fine line printing enhancement, the printed pattern resolution depends on the two factors paste rheology including viscosity, particle size and its thixotropic behavior. The printed pattern for zero wt% of thinner is too thick. Its create bad surface morphology as seen in Fig. 11 through dielectric layers making it difficult to produce high resolution conductor on subsequent layer (Bender & Ferreira, 1994). Furthermore, the transferability of the paste and the uniformity of the conductors degraded when the viscosity is too high (Lahti, 2008).

The flow behavior of the paste during the movement of squeegee is an important factor for the screen printing process. During the movement of the squeegee a whirling of the paste happens which leads to a lowering the viscosity and thus, the paste is to be able to pass a screen meshes (Imanaka, 2005). It is believe that increasing wt% of thinner to the conductor

paste will cause the viscosity of the paste falls so that it can be push through the mesh opening much more easily compared to the paste without thinner.

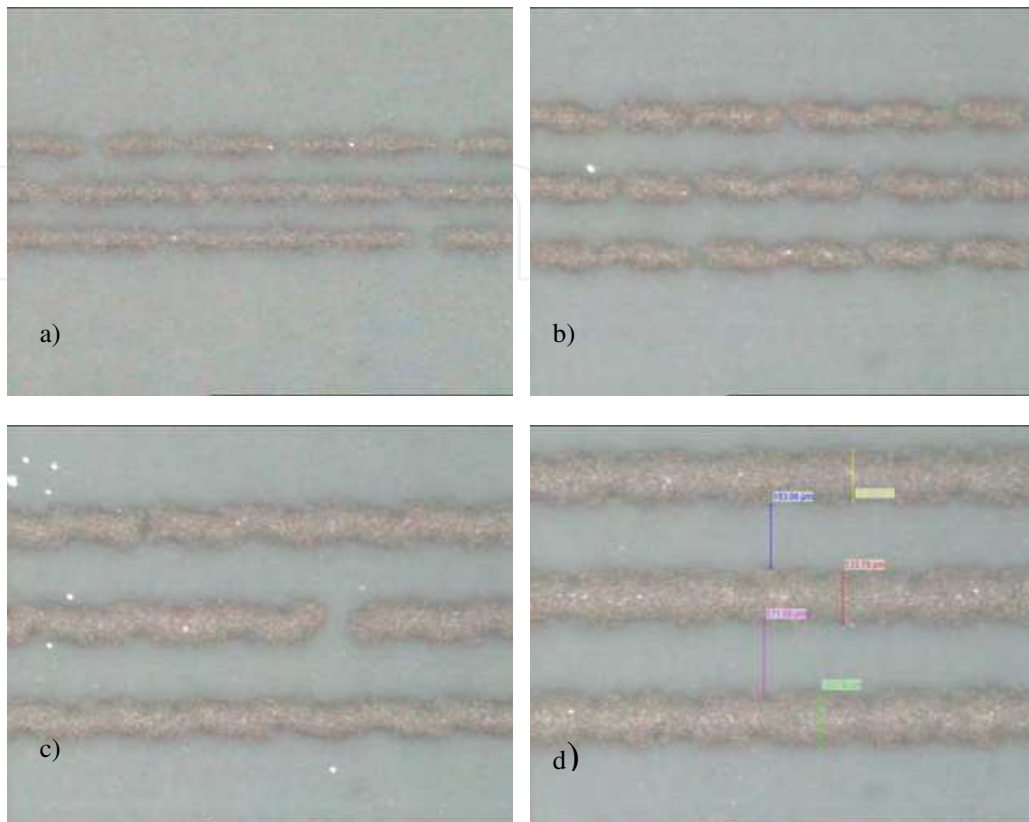


Fig. 10. Line resolution for different width a) 50  $\mu\text{m}$ , b) 75  $\mu\text{m}$ , c) 100  $\mu\text{m}$  and d) 125  $\mu\text{m}$  before firing process

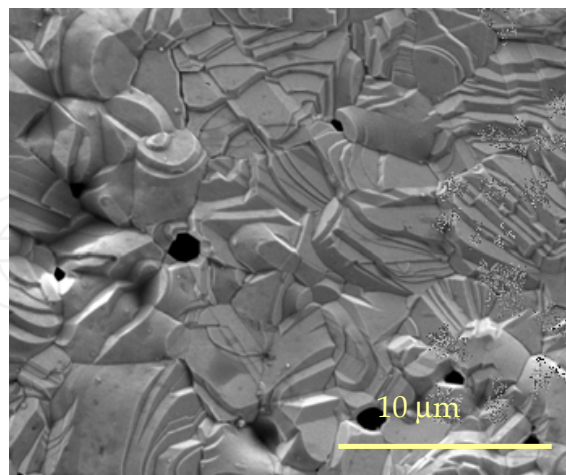


Fig. 11. Surface morphology of conductor paste without thinner

After do some observation, we decide to concentrate on the line width of 100  $\mu\text{m}$  to evaluate the quality of the conductor paste with different percentage of thinner for the horizontal and vertical direction. Fig. 12 presents the representative vertical and horizontal lines of 100  $\mu\text{m}$  line width for the example of 10 % thinner weight percentage. They were observed at 5x

magnification. These picture shows that the screen printed line have smooth line edges and consistent line widths. No paste residue were observed between the lines, thus, these line can be used in the interconnection that require long lines (Wang et al., 2005). It also found that the vertical line resolution is better than the horizontal line resolution. It could be due to the mesh angle (Fig. 13) of the screen mesh parallel to printing in direction. This indicates that the smoothness of the edge printing for sample higher wt% of thinner is not accurate due to the screen wires interfere with the transfer of the viscous paste to the substrate, leaving voids in the printed line.

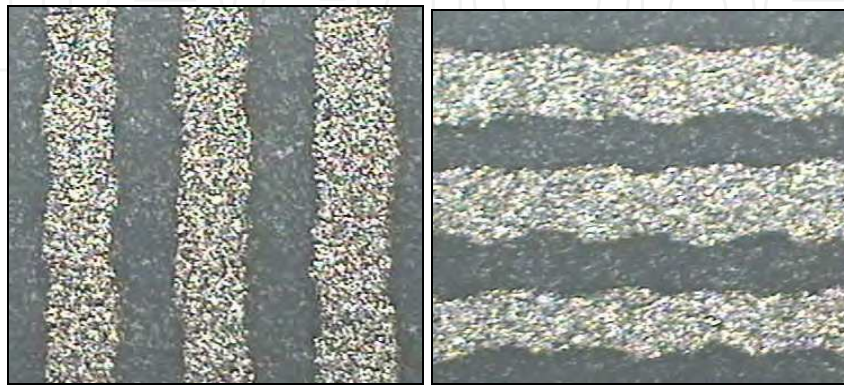


Fig. 12. 100  $\mu\text{m}$  line resolution (after fired) for the silver paste with 10 % thinner weight percentage

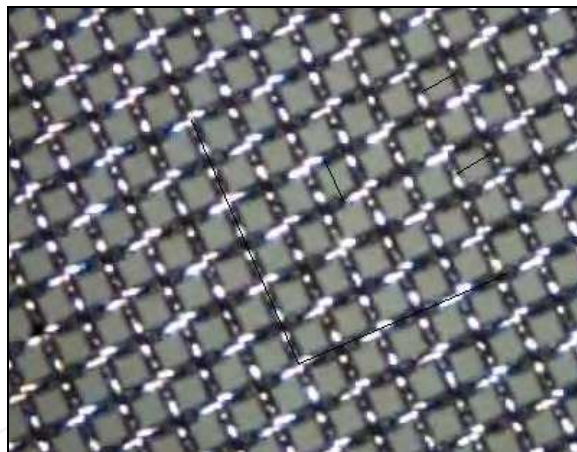


Fig. 13. Screen mesh orientation 325 stainless steel with 22.5  $^\circ$  angles

The effect of screen mesh on printing quality has studied by Stalnecker Jr. (1980) and noted that to get fine line printing the selection of the screen mesh should take into account. The screens for thick film printing should be such that when viscosity and other variables are controlled it should be able to delineate reproducible thickness of the printed line (Dubey, (1974).

#### 4. Conclusion

As a conclusion, the viscosity problem can be solved using the different wt% of thinner (2, 4, 6, 8, 10 and 12 wt %). The phenomena observed from screen-printing pastes are also identical to those reported from literature that the viscosity of the paste throughout the screen-printing

process influences the efficiency of the deposition process and the film's quality. The most higher wt% of thinner pastes have a lower viscosity than those of others at a low shear rate, while their viscosities at high shear rates, which are directly affects the screen-printing quality, are excessively high, resulting in difficult snap off. The thinner may change the thixotropic of the paste and sometimes can change the paste characteristics. So, by changing the thixotropy of the paste, the printing performance can be better. It may also influence the shape of the printed pattern for the non-linearity of the viscosity versus the shear rate. However, many factors such as filler, resin, the solvent system and the solid content influenced the dispersion degree of particles in the paste, resulting in the different of rheological behaviors. The correlation of the paste rheological properties with the pattern transfer efficiency is important to provide better understanding of the effects and the interaction of stainless steel screen mesh process variables to optimize the required printed thickness. Such data will greatly enable the development of more rigorous rheological protocols for the characterization and optimization of the pastes for screen printing in the future.

## 5. Acknowledgment

The authors wish to thank Telekom Malaysia for their funding support under project IMPACT (RDTC/100745) and Assoc. Prof. Dr. Mansor Hashim for the guidance and support for this research work.

## 6. References

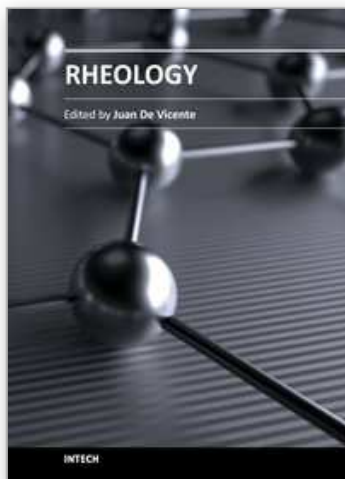
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ISBN 978-953-51-0187-1

Hard cover, 350 pages

**Publisher** InTech

**Published online** 07, March, 2012

**Published in print edition** March, 2012

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