Evaluation of printability of screen- and pad printing inks via high-viscosity piezo inkjet technology

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Abstract

While screen- and pad printing techniques have been established for a long time the automation potential in these fields is limited and the processes require high amounts of manual labor. Piezo inkjet technologies are recently advancing to open possibilities for the use of high-viscosity materials. One potential material class could be screen printing inks that are already established in graphical and functional printing. However, even with the viscosity of these material classes now covered by new printhead technologies the process of implementing a new material for a piezo inkjet process is more complex. This study is outlining the workflow to evaluate a new high-viscosity material for piezo inkjet printing and shows first results for the implementation of two widely used and commercially available screen-printing inks.

Introduction and background

Screen- and pad printing are well-established techniques for the industrial application of labeling and product embellishment. However, the automation potential of these techniques is limited, and the processes still require a high amount of manual labor, while the number of skilled workers is decreasing. Furthermore, the amount of materials used for printing and cleaning is quite high. A reason for the persistence of these techniques against more modern and flexible technologies is their wide range of applicable materials. But as the variety of products expands and the lifetimes of product cycles get shorter, it is difficult to portray these needs through screen- and pad printing [1–6].

One printing technique that offers a high level of individualization and flexibility is inkjet-based digital printing. It is a solution that facilitates quick on-demand production, does not require a printing form, and is contactless. One disadvantage of inkjet printing is the strong limitation when it comes to jettable materials. The maximum viscosity for typical industrial piezo inkjet printheads is around 25

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mPa·s [7]. Recently however, a novel printhead technology has been presented by Quantica GmbH, which is able to jet fluids with a viscosity of up to 250 mPa·s. This increase in processable viscosity is due to a different actuation principle than conventional piezo inkjet. Instead of an acoustic wave generated by the deformation of the piezo actuator, resulting in the ejection of a droplet, the NovoJet system utilizes a piston that is displaced by a piezo element. This results in an actuator displacement that is up to 100 times higher than in conventional printheads. Through this technique the possibility to a whole new range of fluids that could potentially be processed via inkjet is opened [8]. However, even the Quantica NovoJet system has its limitations and requirements for materials that can be jetted. The most important parameters that need to be matched by a material are listed in Table 1.

Viscosity	1-250 mPa·s
Particle size	< 5µm
Surface tension	30-750 mN/m
Jetting temperature range	RT-80 °C

Table 1: Overview of parameters for the Quantica NovoJet system

In this study, the potential printability of two screen printing inks is to be evaluated. This is done by first choosing promising materials for the trials according to their initial properties, such as viscosity, surface tension, or the type of solvent. The next step is to determine if the materials can be diluted to the desired viscosity range of less than 250 mPa·s. If the inks can be brought to the required viscosity, they are further characterized to see if they are fit for jetting trials. This entails testing on the compatibility of the materials with the material supply system and the printhead by Quantica GmbH, particle size and distribution, long term stability of the materials and surface tension.

Materials and methods

The following two screen-printing inks that are described in Table 2 were chosen by our project partner Ritzi Industriedrucktechnik GmbH according to their properties and use cases.

	Material 1	Material 2
Color	white	white
Substrates	PVC (hard and foils), acrylate glass, polycarbonate, polyester foils, thick paper, wood	Glass, ceramics, metals, coated substrates, duroplastics
Areas of application	Labels, Stickers, industrial labelling	Indoor decorations, commercial printing on glass and ceramics
Drying	Physically drying	Chemically curing with hardener
System	Solvent based	Solvent based

Table 2: Overview of material properties of chosen screen-printing inks

Additionally, the thinners provided for the two materials by the manufacturer were characterized.

The first characterization step was the analysis of the particle size and distribution of the two materials via dynamic light scattering (DLS) to ensure the particles are jettable with the nozzle diameter of the printhead. Secondly the viscosity of the materials and thinners was determined with a rotational rheometer (Anton Paar MCR 302) in a cone plate setup with a shear rate sweep from 100-55000 1/s. According to those results the materials were diluted down to have a viscosity lower than 250 mPa·s. This was confirmed by viscosity measurements with the same setup as before. On top of that the stability of the solutions over one week was tested by storing at printing temperature and viscosity measurements. After the appropriate dilutions were prepared, the material compatibility with the components of the material supply system (MMS) as well as the printhead (PH) by Quantica GmbH was tested, and the surface tension was measured.

Results and discussion

The first step in evaluating the jettability of the screen-printing materials is the particle size and distribution. The measurements that were performed via DLS have shown that material 1 has a D_v 90 of 1,1 µm and material 2 of 4,5 µm. Both of those values fit the criteria of the particle size being below 5 µm to accommodate the nozzle diameter of 50 µm of the Quantica printhead. However, the analysis of the size distribution by intensity instead of volume showed small peaks above 5 µm. This could be due to agglomeration of particles and is to be observed during jetting. Generally, the particle size seems to be suitable for jetting trials.

The next step was to measure the viscosity of the materials and their respective thinners.

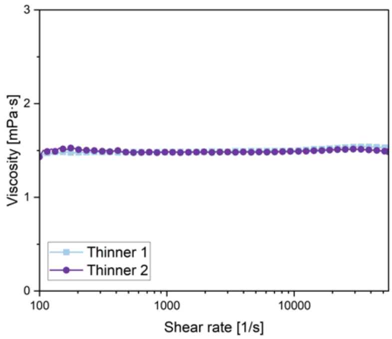

Figure 1: Shear rate sweep from 100-5500 1/s of thinner 1 and 2 at 30 °C

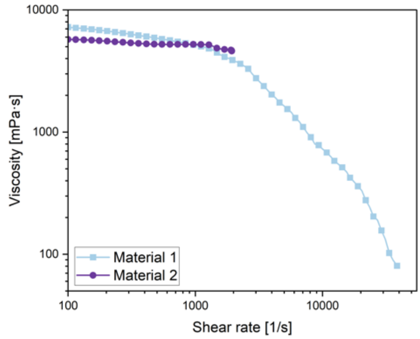

Figure 2: Shear rate sweep from 100-5500 1/s of material 1 and 2 at 30 °C

Material 1 shows a strong shear thinning behavior with a viscosity of around 7000 mPa·s at low shear rates, getting as low as 80 mPa·s at high shear rates. While the inkjet printing process could benefit from this behavior as the droplet is ejected at high shear rates the material still needs to be diluted to a low shear viscosity of lower than 250 mPa·s to ensure a smooth feed of material to the printhead through the material supply system as well as a more stable droplet ejection, as inkjet materials are typically tuned to exhibit Newtonian behavior. Material 2 could not be measured until the high shear range, probably due to high particle content. Both thinners have a viscosity of around 1,5 mPa·s and Newtonian behavior.

According to these results the dilution series were prepared and the viscosity measured under the same conditions. For the further experiments the material 1 and an the respective thinner were chosen due to preferred properties of the ink by the project partner.

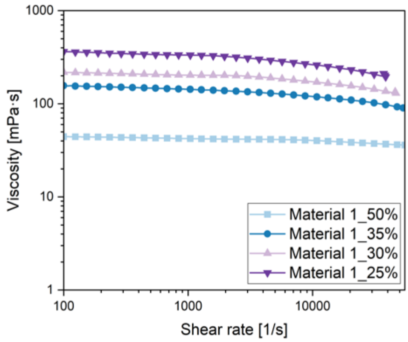

Figure 3: Shear rate sweep from 100-5500 1/s of material 1 in different dilutions at 30 °C

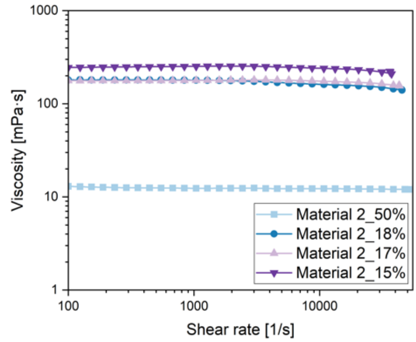

Figure 4: Shear rate sweep from 100-5500 1/s of material 2 in different dilutions at 30 °C

Figure 3 shows the dilution series of material 1 with the appropriate thinner 1. The addition of 25 % of thinner already significantly alters the behavior of the material. The shear thinning is much less pronounced. To achieve a shear viscosity of less than 250 mPa·s, at least 30 % of thinner had to be added. Going forward, a concentration of 35% of the thinner was chosen to allow for potential changes in viscosity. Figure 4 depicts the same process, but with material 2. Here the final concentration going forward was 18 % of thinner.

The next step in testing the now determined dilutions was to analyse the long-term stability of the materials at room temperature and at the estimated jetting temperature of 30 °C, in order to identify changes in viscosity either through prolonged jetting or storage of already prepared dilutions prior to jetting. Figure 5 and Figure 6 depict the viscosity of material 1 with 35 % thinner at different storage conditions after 24 hours and seven days. A drop in viscosity can be observed for both conditions after 24 hours. After seven days, the viscosity increases slightly, but does not exceed the initial viscosity after preparation. This shows that no concerning increase of viscosity is to be expected for storage at room temperature in between jetting trials or during prolonged periods of jetting at 30 °C.

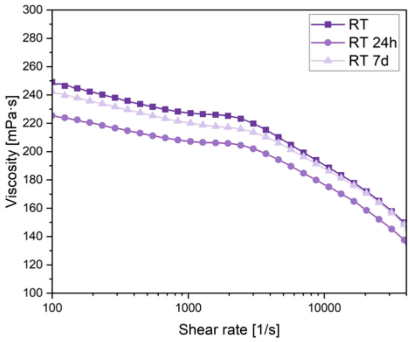

Figure 5: Shear rate sweep from 100-5500 1/s of material 1 different storage times at RT

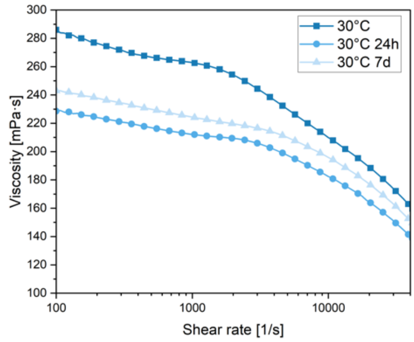

Figure 6: Shear rate sweep from 100-5500 1/s of material 1 different storage times at 30°C

Another important factor before starting any jetting trials with new materials is the compatibility of said materials with the components of the material supply system to avoid any damage to the parts and also to prevent contamination of the jetted material through solvated components. The main components of the MMS and printhead by Quantica GmbH have been summarized in Table 3.

The components are divided according to their location within the system. Also, even though a mixture of material 1 and thinner has already been determined the material compatibility testing was done with both pure components to ensure stability of the system against both individually to determine exactly which material caused compatibility problems.

	Component	**Material 1**	**Thinner**
PH	Polyimide	neutral	good
	Epoxy adhesive	good	good
MMS	Polypropylene	good	good
	Fluoroelastomers	neutral	bad
	PP/EPDM	good	good
	Silicone	good	good

Table 3: Simplified material testing overview for printhead (PH) and material supply system (MMS) components

Most important for the material testing are the printhead components since they cannot be replaced individually. A failure of the glue of the nozzle plate for example would render the whole printhead unusable. Some of the components in the material supply system could be replaced more easily, such as pipes or connectors. However, a good result is still preferred, since ideally, no parts would need to be replaced.

Table 3 shows that the printhead components show sufficient resistance to the materials and during visual examination of the samples no discoloration or swelling was observed. However, one component in the material supply system reacted to the materials by swelling and becoming slightly discolored. Since the fluoroelastomers were only used in easy to access tubes it was not considered a reason to stop with the trials.

Lastly the surface tension of the mixture of material 1 was measured to determine if it fits the range of 30-750 mN/m of the printhead. Measured with a bubble tensiometer the value for the 35% thinner mixture was 27,9 mN/m. It is just below the lower limit, presumably due to the increased solvent content by the thinner. This is not a stopping point for jetting trials however it could be an explanation should wetting of the nozzle plate occur during trials.

Conclusions

In this study a process was outlined that must be performed before being able to do jetting trials with a new material class for high-viscosity inkjet printing. Factors such as viscosity and particle size are most important. Material compatibility and the long-term stability of diluted mixtures is also an important factor for introduction into an inkjet system. In terms of results a conventional screen-printing ink was chosen according to its relevancy for the industry. Material 1 is a widely used ink in many fields. It has been shown that it can be diluted to a viscosity of below 250 mPa·s by adding 35 % of its respective thinner. This mixture with 35 % thinner then proved to be stable in viscosity for at least 7 days at room temperature as well as 30 °C, which would be the estimated jetting temperature. The materials are sufficiently compatible with the material supply system and the printhead. All this qualifies the described dilution of material 1 as a good fit for future jetting trials. The next steps in this project are to determine the parameters required for circulating the mixture in the materials supply system, in order to achieve stable meniscus conditions at the nozzle plate. This will be followed by trials on the possibility of jetting and subsequently waveform optimization to achieve stable droplets.

Acknowledgements

The authors of this study firstly want to thank Ritzi Industriedrucktechnik GmbH for collaborating on this project. Secondly, we want to thank Quantica GmbH for the supply of the material testing kits for their NovoJet System.

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