INVESTIGATING THE RELATIONSHIP BETWEEN NOZZLE SIZE AND PARTICLE SIZE IN INKJET CERAMIC TILE PRINTING

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1. ABSTRACT

Inkjet printing now represents a dominant share of the ceramic tile decoration market. Ink technology has evolved alongside the conversion of this market from large drop binary to small drop greyscale inkjet printing. Ink performance in a given printhead governs the print quality and reliability and inks were developed to accommodate constraints specific to inkjet printers (1). This meant replacing large particle size pastes with low viscosity suspensions of sub-micron particles. The drivers for the use of such small particles were multiple, as using small particles provided increased stability (greater shelf life) of the suspensions and reduced the risk of nozzle blockages.

Most inkjet ceramic inks are pigmented inks, obtained by milling pigments from around 3-10 µm down to less than 1µm. In general, the smaller the particle size of the pigment the narrower the colour gamut achieved. The cost of the ground pigment will depend on the time taken to mill to the required size (2). Thus, the use of inks with larger particle size could lead to economic as well as colour benefits, which would be highly desirable in this market.

While recent improvements in ink formulation have allowed the production of larger particle inks to become a reality, the relationships between maximum particle size, nozzle size and print quality have not been fully investigated. The ratio between nozzle size and maximum particle size is often used to inform printhead and ink development. A conservative figure of 20:1 has commonly been used, without a definite understanding of the relationship between nozzle and particle size, and most importantly, its impact on print quality and reliability.

In this study, four inks for which particle size was adjusted by changing the mill processing time, were jetted using printheads with different nozzle sizes. Every ink presented similar bulk physical properties and low particle aspect ratios; particle size and particle size distribution were the only parameters to be varied. Nozzle to particle size ratios in the range 10:1 to 45:1 were tested in this work.

Drop placement, drop volume, voltage sensitivity and print quality were recorded for various printhead–ink combinations tested.

The lowest nozzle to particle size ratio achieved thus far was 10:1, obtained using an ink with a D_{90} of 1.74µm. This represents the minimum achievable ratio with the current set of printheads and stable inks available and is much lower than the commonly used 20:1 ratio. Stable inks with larger particles are therefore required to test lower nozzle to particle size ratios, while the impact of particle aspect ratio requires further investigation.

2. INTRODUCTION

Inkjet decoration of ceramic tiles is now a well-established and major part of the ceramic tile manufacturing process. Huge progress has been made in the development of printing systems together with advances in ink formulation and piezo print head technology (3). These advances have allowed the ceramic designers to realize ever improving designs and effects. Still there remains a strong desire to even further expand the range of possibilities available so it is a continuing theme of research and development groups to explore ways to deliver alternate materials through the inkjet equipment. One very important aspect which has traditionally been a "problem" for inkjet is the ability to deliver larger particle sizes in a reliable way and that is the subject of this study.

Inkjet printing is used in many areas of decoration from display graphics, label and packaging printing, publication to industrial decoration such as that on wooden décor items. In most applications outside of ceramics any pigmentation of the inkjet inks is with organic pigments of small particle size, typically all the particles being well below one micron in size – "submicron". In ceramics decoration there is of course an entirely different requirement and pigment and/or effect frits are inorganic and typically of larger size. In some cases the desired ceramic effect can only be achieved by the use of larger particle sizes.

The understanding in other areas of inkjet printing is that particle sizes must be kept low and generally a ratio of at least 1:20 with respect to the size of the inkjet printhead nozzles is required. For the ongoing growth of possibilities in inkjet ceramic decoration it is important that continued work take place to challenge this and continue to push the boundaries of ink and equipment.

In this study we examine the performance of a variety of inks of varying size in a range of heads that have a range of nozzle sizes and additionally make suggestions for further work.

3. EFFECTS OF LARGER PARTICLE SIZE IN A CERAMIC INKJET INK

	Positive Effect	Negative Effect
Ceramic Effects	✓	
Cost	✓	
Sedimentation		✗
Nozzle Blocking		✗
Ink Drop formation (Print Quality Effects)		✗

Table 1. *Effects of pigment particle size*

The above table summarises the effects of larger particle sizes. On the positive side there can be more desirable ceramic effects such as stronger colours at lower pigmentation and lower cost due to reduced processing. On the negative side sedimentation can be more severe although can be managed to some extent by ink viscosity and the choice of chemical dispersants as well as agents to structure the ink and reduce the tendency to settle. The additional negative effects relate to how the larger particles interact with the printhead, with in the worst case nozzle blocking and the potential for poor drop formation due to the drop ligament break-off being perturbed.

This paper describes work carried out to address the issues around interaction with the printhead.

4. EXPERIMENTAL

The printhead chosen for the study was the Xaar 1002 which is widely used and well known in the ceramics decoration field. Variants in the form of GS2, GS6, GS12 and GS40 were chosen in order to evaluate varying nozzle size effects.

Head Variant	*Nozzle Size (Microns)*
GS2	18
GS6	26
GS12	35
GS40	47

Table 2. *Xaar 1002 Head variants – nozzle sizes*

The experiments were conducted using a standard Xaar Hydra ink supply system.

The inks were a series of yellows containing Zirconium Praeseodymium Yellow pigment (Pigment Yellow 159) of varying size and a brown Iron Chromite Spinel (Pigment Brown 35) pigmented ink.

Ink	***D90 Size Microns***	***Weight % Solids***	***Surface Tension (mN/m)@ 25C***	***Density(g/ml) @25C***	***Speed of Sound (m/s) @25C***
Y1	1.04	47	30.0	1.35	1170
Y2	1.25	47	30.0	1.35	1160
Y3	1.74	47	30.5	1.37	1180
B1	2.32	43	30.0	1.31	1030

Table 3. *Test ink physical properties*

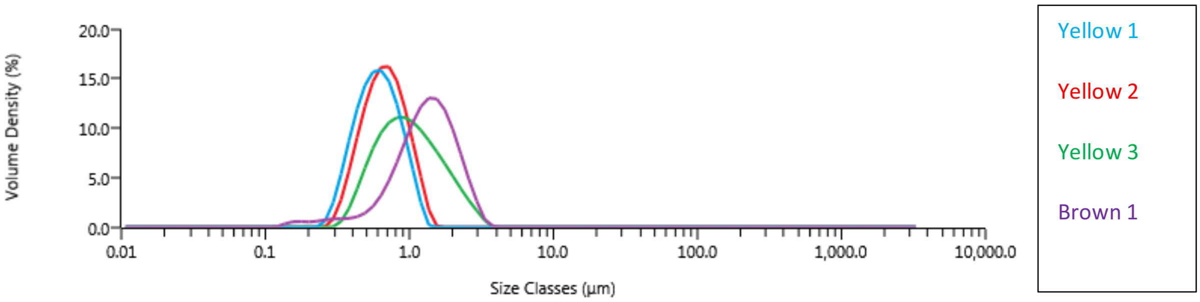


Table 4. *Pigment Particle as measured by Malvern Mastersizer*

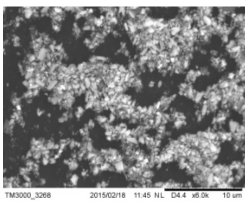
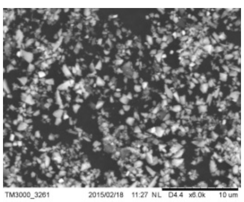
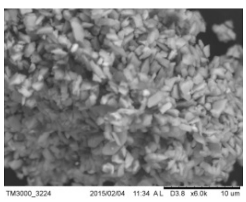
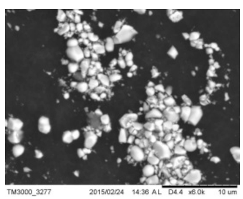
	Yellow1	*Yellow2*	*Yellow3*	*Brown1*
SEM Image X6000 Magnification				

Table 5. *SEM Micrographs of pigment in inks*

The series of inks were all relatively Newtonian in behaviour as shown by the viscosity versus shear rate plot below:

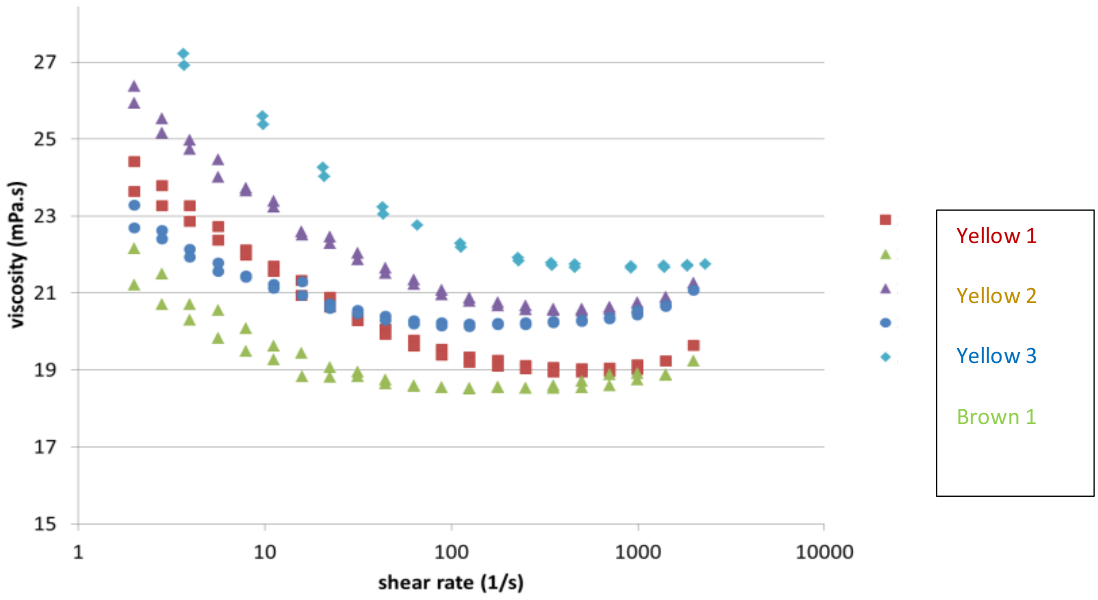


Table 6. *Viscosity versus shear rate for trial inks*

5. RESULTS AND DISCUSSION

The four inks with varying particle size distribution were tested in the differing Xaar printheads. Every ink presented similar bulk physical properties as can be seen above; however the largest particle size ink (Brown 1) wasn't stable and showed obvious signs of sedimentation, which was the cause of some unreliable printing.

Drop placement, drop volume, voltage sensitivity and print quality were recorded for the various printhead–ink combinations tested. Table 7 provides a summary of the jetting results. Print quality evaluation and scoring in the table are as follows: good image= (✓), high number of tick marks (>100) at 100% duty but reliable at less than 100% duty= (✓), bad (×).

Yellow 1 is considered the reference point: this is a very good standard ink with a D90 around 1µm. The jettable viscosity range was tested using this ink: using a similar drive voltage, a similar drop volume and velocity was obtained for viscosity values ranging from 25 to 36 mPa.s. Yellow 2 and Yellow 3 were printed with GS40 at a slightly lower viscosity, which may explain the moderately lower print quality at 100% duty. Ink Brown 1, with the largest particle size, was causing serious problems, so far being attributed to the intrinsic instability of the ink. The drop placement results (not shown here) were considered normal for every ink/printhead combination tested.

Drop volume and voltage sensitivity seem independent of particle size when printing with GS2 (~ 6% variation between Yellow 3 and Yellow 2), whereas with GS40 the voltage sensitivity drops by around ~ 44% between these two inks. As a result the drop volume at 4 dpd with GS40 drops from 149pL to 110pL. There is no clear trend i.e. the drop volume doesn't correlate with particle size. Further investigation is required to determine where this drop volume is lost but the current hypothesis is that ligature break up is affected by the particle size in conjunction to the nozzle size (and hence initial ligature width) which leads to smaller drops with GS40.

The highest particle to nozzle size ratio was obtained with GS2, setting the current limit between 1:10 and 1:11. This represents the maximum achievable ratio with the current set of printheads and stable inks.

D_{90} (µm)	1.04 Yellow 1	1.25 Yellow 2	1.74 Yellow 3	2.32 Brown 1
GS2	n/a	✓ Good reliability @ 6kHz pL/V=3.1 Drop Volume (pL) at max dpd= 21	✓ Good reliability @ 6kHz pL/V=2.9 Drop Volume (pL) at max dpd= 20	n/a
GS6	✓ Good reliability @ 6kHz	n/a	n/a	n/a
GS12	✓ Good reliability @ 6 and 12 kHz	n/a	n/a	n/a
GS40	✓ pL/V=16.0 Drop Volume (pL) at max dpd= 149 Good reliability @ 6 kHz for viscosity 25-36 mPa.s High tick count @ 6kHz for ink viscosity of 23 mPa.s, when running a 100% duty image. No ticks observed in other images or degradation of print with increased viscosity.	✓ pL/V=6.3 Drop Volume (pL) at max dpd=110 High tick count @ 6kHz, for ink viscosity of 23 mPa.s with 100% duty image and in 4dpd area of Standard Test Pattern (STP) images. Few ticks observed in other images. Increased tick count in STP image print with increased viscosity.	✓ pL/V=11.3 Drop Volume (pL) at max dpd= 120 High tick count @ 6kHz and ink viscosity of ~ 22 mPa.s with 100% duty image. STP images have several short-medium ticks. Little increase in tick count in STP image print with increased viscosity.	× (Ink issue) Jetting unreliable @ 6 kHz, viscosity ~20 mPa.s. Under increased duty gets worse with each DPD level making drop volume data lower than expected. With increased time in Hydra circulation (~5 days) ink stabilised under duty but volumes derived were 20pl/dpd suggesting it is a consequence of settling of solids/change in density.

Table 7. *Jetting performance summary*

Particle:nozzle size ratio	1.04 (µm)	1.25 (µm)	1.74 (µm)	2.32 (µm)
GS2	n/a	1:15	1:10	n/a
GS6	1:25	n/a	n/a	n/a
GS12	1:33	n/a	n/a	n/a
GS40	1:45	1:37	1:27	1:20

Table 8. *Maximum Particle:Nozzle Ratios achieved*

6. CONCLUSION AND NEXT STEPS

Inks were successfully jetted at significantly greater particle size than would have previously been considered, that is with a lower ratio of particle to nozzle size, the lowest being 1:10 for the GS2 printhead. Further work is needed to find the limits, particularly for the GS40 printhead, but tentatively we can conclude that d90 particle sizes significantly in excess of 2 microns should be useable. Such inks could have advantageous properties in terms of their ceramic decorative effects or offer significant economic benefits in the inkjet decoration of ceramic tiles.

Unfortunately, the inadequate stability of the large particle size Brown 1 ink inhibited reaching conclusions at even lower particle to nozzle ratios in these tests.

Stable inks with larger particles are therefore required to test higher particle to nozzle sizes ratios and more work will be needed to stabilise such inks. This is very likely to come from either an increase in ink viscosity (but ideally within the range tested with the standard ink, i.e. up to 36mPa.s) or the move to non-Newtonian shear thinning inks.

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