UV white inkjet inks for single-pass label applications

Mark Ritchie, Product Manager, Xaar plc

Introduction

The label industry has traditionally used white ink printed as a solid block underneath images and text on clear labels to make them contrast strongly against the product packaging they are applied to (see **Figure 1**). Without a background white, colours can appear dull or even disappear and affect the product's shelf impact and consequently brand value (see **Figure 2**).

White background Dark background

Figure 1: Images printed over white give impact even over dark background

White background Dark background

Figure 2: Images not printed over white disappear over dark background

UV flexo and UV screenprint technologies have been widely utilised to print these opaque whites, however digital and particularly inkjet options are growing in popularity.

The first single-pass inkjet whites for label printing were introduced by Durst and EFI at Labelexpo 2009 with their Tau 150 and Jetrion 4830 label presses respectively. Both of these benefited from the Xaar 1001's capability to reliably jet highly pigmented inks. The Jetrion 4830 made such an impression that it was named winner of the Label Industry Award for New Innovation at the exhibition.

Since then the number of inkjet label presses with a white option has increased significantly to the extent where a high performance, opaque white capability is now regarded as a key measure of the overall performance of a UV inkjet label press.

This paper explores the challenges in formulating opaque white inks for the low viscosity requirements of inkjet printheads and the impact this can have on overall ink performance.

Formulating a UV white ink

The key differences of a UV white ink compared to process colours are its large, heavy pigment particles which are liable to sediment. This makes the development of UV white inks for single-pass inkjet printing a major challenge.

The challenge does not end with the pigment, and to understand this more fully it is useful to discuss the individual components of a typical pigmented UV curable ink (see **Figure 3**), which include:

- Oligomers: impart the basic performance properties of the cured ink, including its adhesion range and flexibility
- Monomers: have the major function of providing lower ink or coating viscosity
- Pigments: give the correct colour
- Photoinitiators: ensure UV-curing is achieved
- Additives: fine-tune ink performance, e.g. defoamers, wetting agents and dispersants.

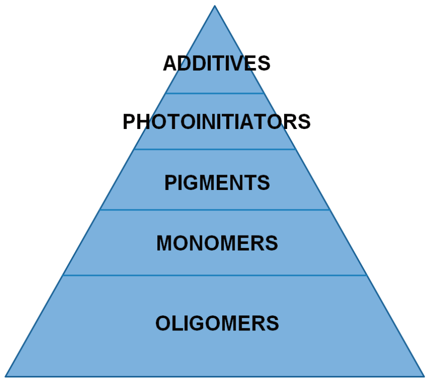

Figure 3: Typical formulation of a UV curable ink

Each component plays an important role in optimising the performance properties of the final ink formula. However, balancing the sometimes contradictory requirements of the raw materials, such as viscosity versus pigment content, raises a number of technical issues that an ink manufacturer must take into account, particularly when formulating a low viscosity, high opacity UV white ink.

These issues tend to be compounded when the inks need the additional functionality required for packaging applications such as label printing where the final properties include adhesion to synthetic substrates, physical or chemical resistance, and the capability of being over-printed.

White pigments

Titanium dioxide (TiO_2) is the pigment of choice for white inks, paints and coatings primarily because of its optical properties, including its high refractive index (see **Table 1**). TiO_2 is unique because it efficiently scatters visible light, thereby delivering the whiteness, brightness and opacity of an ink. The scattering of visible light is maximised at a pigment particle size of 200-300 nanometres (nm). This is significantly larger than other UV colours which are normally less than 200 nm.

White pigment	Refractive index
Rutile TiO_2	2.73
Anatase TiO_2	2.55
Antimony Oxide	2.09-2.29
Zinc Oxide	2.02
Basic Carbonate, White Lead	1.94-2.09
Clay	1.65
Magnesium Silicate	1.65
Barytes ($BaSO_4$)	1.64
Calcium Carbonate ($CaCO_3$)	1.63

Table 1: Refractive indices of white pigments

These pigment features are needed to ensure a bright, clean colour and so that the ink's opacity, or hiding power, allows it to be overprinted with transparent trichromatic colours without reducing the impact of the image.

However, the use of titanium dioxide results in one of the biggest challenges that ink formulators face in developing the low viscosity inks needed for inkjet printing: overcoming gravitational settlement of the large and dense TiO_2 pigment particles. As a general rule the lower the ink viscosity the more prone the pigment is to settlement. This is because the density differential between the pigment particles and the other ink components increases.

White ink formulation is made particularly difficult as a high pigmentation level is needed to ensure a white ink has sufficiently high opacity. Furthermore, this has to be achieved while maintaining all other ink properties including: viscosity, surface tension, particle size, cure speed, adhesion range, flexibility, jetting reliability and drop formation / break-off.

Ink manufacturers focus significant R&D resource into optimising white dispersion stability. Formulations are designed to minimise settlement as much as possible, but also to ensure that should settlement occur the ink can be readily re-dispersed through agitation.

Formulation strategies include the use of specialist chemicals such as dispersants which coat pigments to improve the separation of particles, prevent settling and reduce interparticulate attraction within the dispersion itself. The selection of the appropriate raw materials to maximise pigment stability and content level in a low viscosity ink is critical.

Sedimentation

Even the most stable UV white ink will experience some degree of pigment settlement over time if it is left undisturbed. This is why ink manufacturers recommend shaking UV white inks before use and also that they are recirculated during use.

A recirculating ink supply system which keeps the ink in constant movement is essential to ensure that sedimentation is minimised; filters can be used to contain any pigment build up that occurs. However, sedimentation within a printhead itself can lead to serious print problems including nozzle deviations and blocked nozzles which will result in highly visible missing lines in single-pass images. If the source of the blockage is temporary, the missing lines may be short-lived and result only in lost print. If the nozzles cannot be recovered then replacement of the printhead is the only possible solution.

Minimising the possibility of sedimentation within a printhead is therefore an important requirement to ensure ongoing print reliability and acceptable printhead life.

Traditional end-shooter printheads have no internal ink recirculation capability. The ink enters the printhead through the ink supply channel, and exits via the nozzle only when jetted (see **Figure 4**). This means that ink is not kept in a state of constant movement and is at risk of settling out in the ink chamber potentially leading to blocked nozzles.

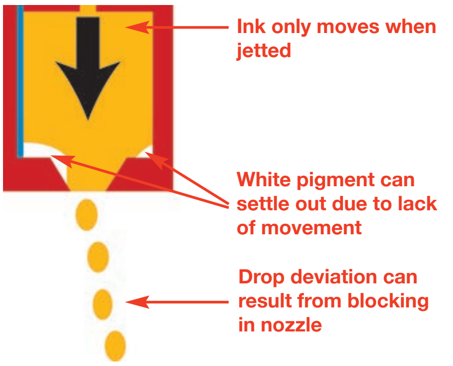

Figure 4: Ink sedimentation in end-shooter printhead

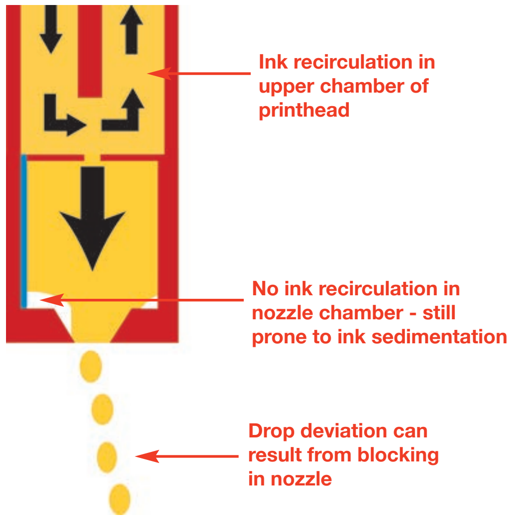

Figure 5: Ink sedimentation in end-shooter printhead with internal ink recirculation

Alternative end-shooter printhead architectures incorporate ink recirculation in an upper chamber within the ink manifold. However, the ink flow remains external to the nozzle chamber which therefore still remains a 'dead spot' within the printhead (see **Figure 5**). As with traditional end-shooter printheads, ink sedimentation can be difficult to avoid.

Xaar's unique TF Technology™ and Hybrid Side Shooter™ architecture used in the Xaar 1002 ensure continuous ink flow at a high rate through the entire printhead, and directly past the back of the nozzle during drop ejection. The high circulation rate not only ensures that any air bubbles and unwanted particles present in the fluid are carried away, but also keeps heavily pigmented and high density inks in constant movement preventing sedimentation. This radically improves jetting reliability and significantly reduces the likelihood of temporary or permanent nozzle deviation and blocking compared to end-shooter architecture (see **Figure 6**).

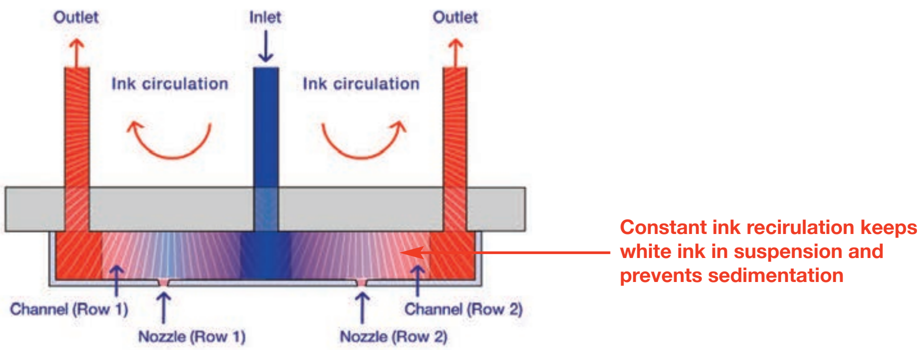

Figure 6: Constant ink recirculation prevents ink sedimentation and consequential nozzle blocking

It has already been stated that as ink viscosity reduces it becomes more difficult to maintain its stability, making it more susceptible to sedimentation and increasing the potential for jetting reliability issues or premature printhead failure. Printheads that have restrictions to the ink viscosity levels they operate with therefore make the task of developing a UV white ink with sufficient pigment to give high opacity extremely challenging.

An additional benefit of the Xaar 1002's patented printhead architecture is that it offers a wide ink viscosity operating window: from 7 to 25 centipoise (cPs). This gives ink manufacturers the freedom to develop higher viscosity inks which are more stable and less likely to sediment.

Measurement of opacity

Opacity is defined as 'the ability of a coating to prevent the transmission of light', and the terms 'hiding power' or 'contrast ratio' are also used as alternative descriptions in the print industry. The greater the opacity of a white ink, the more efficient it will be at hiding an underlying colour.

BS 3900-D4 (also known as ISO 2814) is a standard used for comparing the opacities of inks. This standard describes how a film of ink is applied to a black and white patterned substrate and dried or cured. A spectrophotometer is used to measure the amount of light reflected, the Y reflective values, from the over coated black (Yb) and white (Yw) areas of the substrate. This is then expressed as a percentage ratio:

$$\textit{Opacity}\ (\%) = \frac{Yw}{Yb} \times 100$$

An ink which is totally opaque will obscure the black and white areas to an equal extent. In this situation, equal amounts of light will be reflected from the over coated black and white areas, the Yb and Yw reflective values will be identical, and consequently an opacity value of 100% will be obtained.

Although BS3900-D4 uses Y reflective values to measure opacity, the L* value is often used in its place. Opacity measurements using L* values are higher than those obtained using Y reflective values and can give a misleading perception of opacity. It is therefore important to know which method has been used when comparing opacity between inks and processes.

All UV white inks use the same grade of TiO_2 pigment, therefore differences in opacity between inks is determined by a combination of the pigment loading and the cured ink film thickness. below gives a summary of these differences between inks used for digital inkjet and analogue printing and the opacity values that can be typically achieved.

Print technology	Typical pigment loading	Typical ink film thickness	Typical opacity values		Comments
			Y reflective	L*	
UV rotary screen	≥36%	10 µm	87%	95%	Single-pass
UV inkjet: Xaar 1002 GS6	≥30%	8 µm	84%	94%	Single-pass – 1 printbar
UV inkjet: low viscosity printhead *	≥20%	14 µm	84%	94%	Single-pass – 2 printbars
UV flexo	≥50%	4 µm	80%	93%	Single-pass

* Ink viscosity requirements ≤7 cPs

Table 2: Refractive indices of white pigments

Where there are limitations to the ink volume and therefore cured film thickness that can be printed, as with UV flexo, a higher pigment loading is used to give an acceptable level of opacity. Conversely, where there are constraints on the level of pigment loading, as with a printhead which requires the use of very low viscosity inks, the ink film thickness must be increased to maintain opacity.

The above data illustrates that inkjet is a real commercial alternative to printing opaque white inks with traditional analogue techniques. It also clearly demonstrates the difference in opacity values measured using Y reflective values versus L* values.

Opaque inkjet inks

The viscosity of an ink not only affects its propensity to sediment, it also governs the level of pigment loading and therefore opacity that can be achieved. This means that the maximum pigment loading of an ink is limited by the ink viscosity requirements of a printhead. The lower the viscosity of an ink, the lower the level of possible pigment loading, and the lower the opacity level achieved.

As the Xaar 1002 has the capability to jet higher viscosity fluids, UV white inks can be designed with a pigment loading high enough to achieve an opaque white in single-pass operation with a single printbar.

Printheads which require a UV white ink with a viscosity lower than 7 cPs will typically contain 35% less pigment than an ink designed for use with the Xaar 1002. This significantly reduces achievable opacity.

One solution to this problem without resorting to multiple print passes is to double-hit the white by adding a second white printbar, which clearly adds significant cost. This will increase the opacity level to what is typically achieved using a single printbar of Xaar 1002 GS6 printheads in single-pass operation, but will result in a thicker overall ink film.

This difference is clearly visible from the photographs in **Figure 7** and **Figure 8**, imaged using a Hitachi TM3000 Scanning Electron Microscope. The film thickness of the ink printed with a lower viscosity ink and double printbar (see **Figure 7**) is between 13.4 and 13.7 µm – nearly twice that of the 7.2 to 7.5 µm of higher viscosity, more highly pigmented ink printed with a single printbar using Xaar 1002 GS6 printheads (see **Figure 8**).

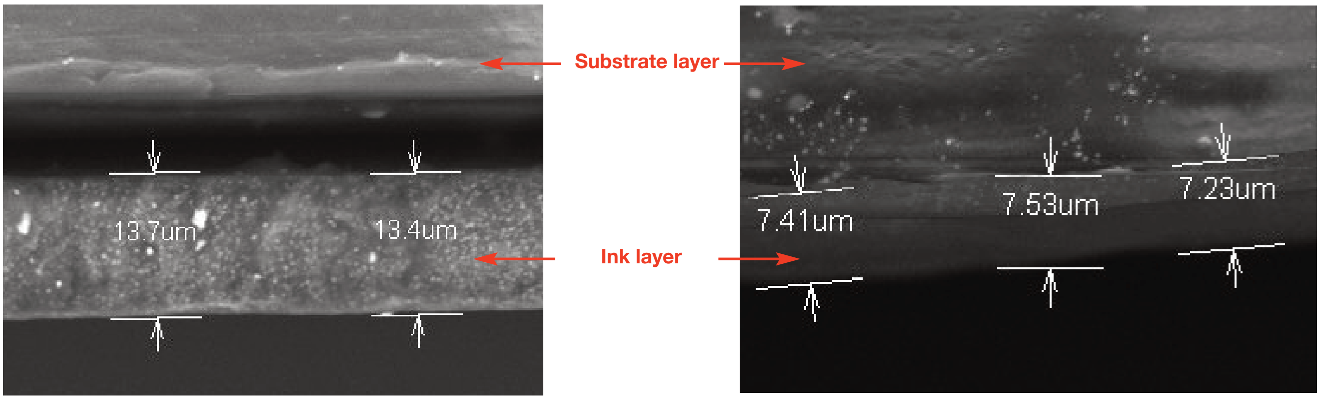

Figure 7: White ink film printed with double printbar

Figure 8: White ink film printed with single printbar

There are a number of downsides to the additional ink film thickness which the lower pigmented ink and double printbar approach typically brings as summarised in **Table 3**.

	Single printbar – Xaar 1002 GS6U printheads	Double printbar – low viscosity (non-Xaar) printheads
Pigment loading	≥30%	≤20%
Ink film thickness	7-8 µm	13-14 µm
Capital cost	Single printbar only	2 x single printbar
Ink cost	Half x double printbar	2 x single printbar
Ink cure	Easy to achieve full through cure with thinner ink film	More difficult to achieve through cure with thick ink film
Adhesion to substrate	Excellent	More difficult to achieve
Ink film flexibility	Excellent	Thicker ink film less flexible

Table 3: Constraints of using double printbar to achieve opacity through high ink film thickness

The most obvious of the disadvantages are that the use of an additional printbar adds to the capital cost of the equipment, and that printing twice the volume of ink doubles the ink cost per label.

In addition, cure speed and especially cure at the base of the ink layer can also be compromised. In order to cure the ink fully, sufficient UV light has to be able to travel right through the ink film to the substrate surface. As TiO_2 is a strong absorber of UV light the curing power of UV light is reduced as it travels through the ink towards the substrate. Curing an ink film which is twice as thick requires UV light not only to travel through the light-absorbing pigment, but also double the distance. Failure to get sufficient UV light to the base of the ink film will prevent full ink cure resulting in poor adhesion to the substrate and leaving the residual odour of uncured ink in the print.

Furthermore a heavy ink deposit can also lead to increased film brittleness. When a printed substrate is bent or shaped onto a curved surface it can lead to the ink film cracking and delaminating. This is an issue which is made worse when printing onto a thin substrate where the thermoplastic UV ink forms a high proportion of the total label thickness.

The following pictures demonstrate the differences in flexibility of the different ink film thicknesses as shown in **Figures 7** and **8**. Both are images of solid areas of cured UV white ink printed single-pass onto pressure sensitive clear polypropylene film. Ink flexibility was tested by folding the printed substrate 180 degrees. All pictures were captured using a Hitachi TM3000 Scanning Electron Microscope.

Figure 9: 8 µm ink film printed with single printbar of Xaar 1002 GS6 (200x magnification)

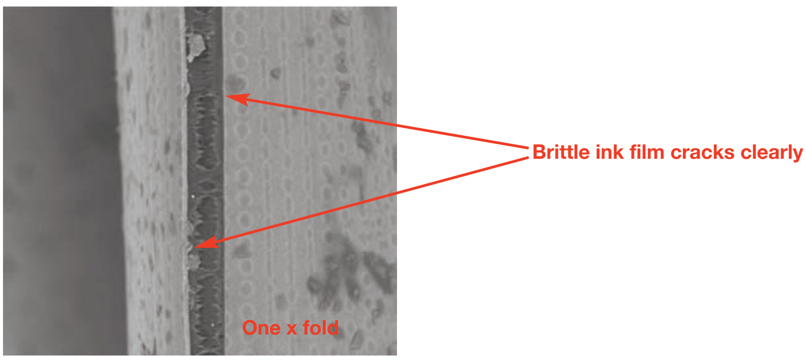

Figure 10: 14 µm ink film printed with double printbar of non-Xaar printheads (200x magnification)

The substrate printed using the Xaar 1002 GS6 (see **Figure 9**) was subjected to three cycles of folding. It can be seen that the ink film remains fully adhered to the substrate and shows no sign of cracking and brittleness.

However, after only one fold of the substrate printed with the thicker ink film (see **Figure 10**) it has visibly cracked. When this image is viewed at 500x magnification (see **Figure 11**) the brittleness of the ink film can be clearly seen by the clean nature of the cracking.

Additional issues also become apparent in this view: the ink is not fully cured potentially releasing non-polymerised oligomers, monomers and photo initiators to migrate through the label packaging; and the ink film has lifted away from the substrate indicating poor adhesion.

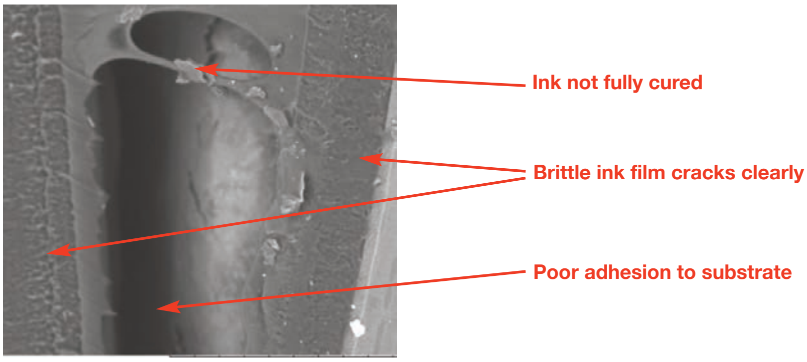

Figure 11: Opaque white ink printed with double printbar (non-Xaar printheads – 500x magnification)

The compromises that are made to ink flexibility and adhesion through building up the ink film thickness to achieve an opaque white are evident. This clearly has implications when labels are applied and used in real-life situations, and will affect brand quality perception. And not forgetting uncured UV ink has health & safety implications.

Formulating for adhesion and flexibility

We have already discussed the difficulties of formulating a white ink in terms of opacity and pigment sedimentation. But there are other challenges which an ink formulator has to face when developing low viscosity inkjet inks.

The chemist not only has to ensure that the pigment loading is as high as possible to maximise opacity and that the ink remains stable in suspension. He also has to ensure that the ink can jet reliably and that print performance requirements such as adhesion to specific plastic substrates and ink film flexibility are achieved.

Aside from photoinitiators, the main functional elements of an ink are the monomers and oligomers. The chief task of monomers in the ink formula is to lower viscosity and they are therefore a vital component for the low viscosity requirements of inkjet inks. Oligomers, often acrylated resins, provide the major functional part of the formula and determine the adhesion and flexibility properties of the finished ink.

Oligomers are generally of a high relative viscosity and there are therefore limits to the amount that can be used in inkjet ink formulations. The capability of the Xaar 1002 to jet higher viscosity fluids allows ink chemists greater freedom in selecting suitable oligomers and using them in sufficient concentration to ensure the cured ink has a wide adhesion range and remains flexible.

It also means that the use of oligomers is restricted in fluids formulated for printheads that require lower ink viscosity than the Xaar 1002. This in turn limits the functionality of the cured ink and can result in a brittle ink film and poor adhesion to certain substrates. This formulation restriction could be a contributing factor to the poor ink functionality seen in **Figures 10** and **11** compared to that in **Figure 9**.

Overprinting whites with process colours

The impact of a 'no look' label is maximised when a four colour image or text is printed over a white as it makes the colours more intense and ensures contrast with the background. It is possible to create a design which does not overlay the colours on top of the solid white ink and this may show good contrast when viewed against a neutral opaque background.

Figure 12 below shows two labels printed onto clear pressure sensitive material: the process colours in example a) are printed directly onto the substrate with no background white and the colours in example b) are printed over an opaque background white. Even on a neutral background, the colours which are overprinted on white ink in example b) are visibly brighter.

a) Image printed directly onto clear substrate – no background white

b) Image printed directly over white

Figure 12: 'No look' labels viewed against a neutral opaque background

When the same images are viewed against a non-neutral background, for example yellow in **Figure 13**, the difference becomes even clearer. The transparent process colours which are printed directly onto the clear substrate (a) are overpowered by the background whereas those printed over white (b) continue to stand out.

a) Image printed directly onto clear substrate – no background white

b) Image printed directly over white

Figure 13: 'No look' labels viewed against a yellow background

The benefit of the inkjet white printed below the images becomes even clearer when viewed against a black background (see **Figure 14**). Only the white ink itself stands out on example a), whereas on example b) all images and text, white and process colours, remain clearly visible and strongly contrasted to the background.

a) Image printed directly onto clear substrate – no background white

b) Image printed directly over white

Figure 14: 'No look' labels viewed against a black background

Summary

There are clear challenges in optimising the print process to meet the requirements of label printers. Specifically they require an opaque UV white ink that adheres well, can be fully cured and is flexible, all in a single-pass. The key elements in the digital inkjet process – ink formulation, printhead, ink recirculation and UV curing systems – all play a major role in ensuring optimal press performance. It is vital that the print process ensures the white ink:

- Has good opacity to ensure contrast on 'no look' type labels
- Remains in suspension so that damaging sedimentation in the printhead or recirculation system is avoided
- Jets reliably through the longest print runs and avoids rejection of jobs due to lines in the print
- Retains performance characteristics necessary for label applications including
    - adhesion to a wide range of synthetic substrates
    - film flexibility to prevent cracking when bent or folded
    - the ability to be overprinted with images and text to give strong image contrast.

The architecture of the Xaar 1002, with its inherent capability to jet inks with a wide range of viscosities and its unique TF Technology™ (constant ink recirculation at a high flow rate through the printhead itself), ensures that these challenges are minimised. Ultimately, this is why the Xaar 1002 has become the first choice for single-pass printing of digital inkjet UV white inks today.

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Head Office / Europe + 44 1223 423 663 info@xaar.com
Hong Kong + 852 3690 8555 info@xaar.com **USA** + 1 972 606 2520 americas@xaar.com
India + 91 124 668 8055 india@xaar.com
www.xaar.com

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