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Automated color printing of glass by using a laser-burning process

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Abstract

In recent years, the production of individual, colored glass products has been increased. As a result, flexible production processes and short delivery times for glass finishers should be profitable. Currently, the colors have to be applied on the glass surface before tempering in the oven. As a result, the color will be burned with the glass. Therefore, the process is reserved for large companies with an oven for the production of toughened safety glass. In this project, a new process will be developed. The applied color is baked locally on the glass surface by laser radiation. Float glass was used for the investigations. Laser firing experiments were carried out with different color layers with thicknesses of about 30 µm. A coloring could be achieved by using a laser wavelength of 10.6 µm. The process limits were determined and the following phenomena were observed: no coloring is possible with low material stress; with adapted laser parameters, a coloring is visible; with an increase in the laser power, stresses in the glass were introduced. Therefore, the risk of crack initiation will be increased. The colors created with the oven fired process and with the laser process have identical appearances. Using the laser process, different colors could be burned locally on the glass surface and the production of large-format and colored images, for example in architectural glass, are possible.

Keywords: glass; printing techniques; surface treatment

1. Introduction

For the coloring of glass, various colors such as ceramic inks and laser colors are known. Ceramic inks are used for digital printing with a tempering process in an oven. The glass has to be cleaned and then positioned on the glass printer. Ceramic inks are printed on the glass, and have to be dried in the dryer and

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then transferred into the tempering furnace. During the tempering process, ceramic inks are fused into the glass itself. The burned colors on the glass are resistant to scratching, acids, UV light and environmental conditions. Therefore, digital glass printing with its durability is suitable for applications in architectural buildings.

Some pigment and color producers offer colors especially for the laser marking of glass. These colors are mostly applied by an airbrush system on the substrate. In general, lasers such as CO_2 lasers, Nd:YAG lasers, and fiber lasers are recommended by the producers. The laser generated colored markings on glass which are contrast-rich and resistant to environmental conditions such as to UV light, abrasion, strong acids, bases, organic solvents and extreme temperatures.

This research is intended to investigate which colors are suitable for a laser burn-in process. So, the advantage of the automation and the local burn-in by laser can be combined to conserve resources. In addition, a possibility is to investigate, if the laser colors could be burned, so that multi-color glass print images could be created. In this study parameters for the laser burning of colors will be determined.

2. Experimental setup and procedure

2.1. Material

Different colors such as marksolid black, and marksolid green have to be applied on float glass with a thickness of 4 mm. Before coating, the glass is cleaned with alcohol, so that a dust-free surface can be ensured. Then the typical coating techniques, airbrush and screen printing, are used to apply the colors on the cleaned glass surface. After that the colors have to be dried for about three minutes. Recommended layer thickness of the color is approximately 30 µm. But in the study, the coating thickness is also varied. Then it is prepared for the laser-burning process.

2.2. Laser

A pulsed CO_2 laser is used for the laser burning experiments. This CO_2 laser has a wavelength of 10.6 µm. The laser beam, with a focus diameter of approximately 300 µm, is focused onto the surface of the glass by a galvanometer scanner. The scanning field is about 300 mm x 300 mm. By using the graphical user interface, the layout is set to a size of 5 x 5 mm. Then the laser beam is guided bidirectional meandering in a parallel hatching. The hatch is the distance between two adjacent lines. The duty cycle, mostly in percentage, is the ratio of the pulse active time and the total period of the signal. Table 1 shows an overview of the experimental laser parameters.

Table 1. Overview CO_2 laser parameters

Laser parameter CO_2 laser pulsed			
Frequency	f_{rep}	kHz	10, 30, 50
Duty Cycle	DC	%	4 to 10
Scan velocity	v	mm/s	300 to 2000
Hatch	h	mm	0.1 to 0.2

3. Results and discussion

In the following, the different results of the laser tempering of colors such as black and green on float glass are presented.

3.1. Laser tempering of black color

Table 2 summarizes the results of the CO_2 laser of marksolid black which was applied by airbrush on float glass. The scan velocity is constant at 1200 mm/s and the hatch is 0.2 mm. The process limits were determined by optical microscopic analysis and additionally by a scratch test on the glass surface. Evaluation methods are used to decide, if a color is burned-in. Hence, the following sections can be divided by the parameter study.

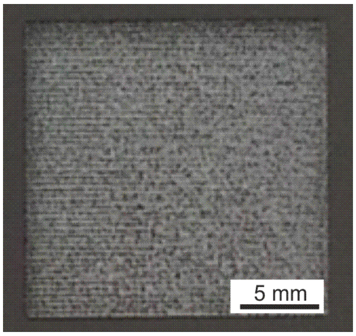
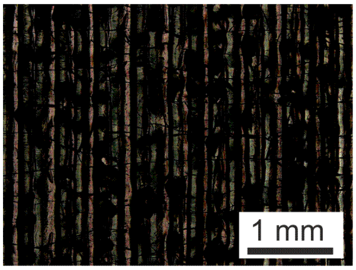
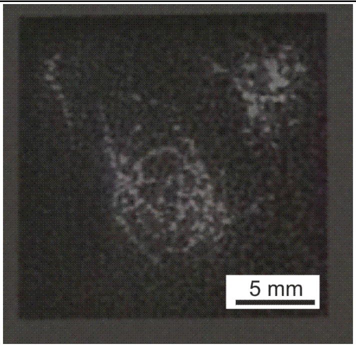
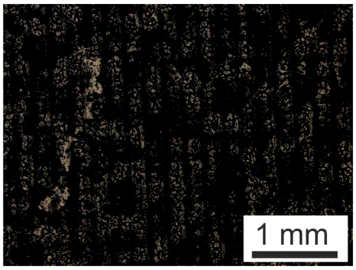
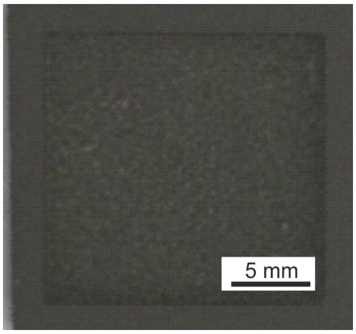
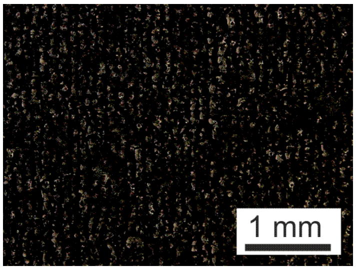
No burn-in of the color is observed at a low frequency of 10 kHz and a duty cycle of 4 %. When increasing the duty cycle to 7 %, delamination is visible. The authors expect that the delamination and also the damage of glass substrate occur due to temperature difference between the color and the glass is too great. A burn-in of the marksolid black color is achieved at a frequency of 30 kHz, and a duty cycle of 6 %.

Table 2. Parameters for the burn-in of marksolid black on glass applied by airbrush, with CO_2 laser;
v = 1200 mm/s; h = 0.2 mm

Frequency (f_{rep})	10 kHz			30 kHz			50 kHz		
	DC in %	Result	Color	DC in %	Result	Color	DC in %	Result	Color
	4	no burn-in		6	burn-in	black	5	delamination	gray
	5	burn-in		9	delamination		10	delamination	
	6	burn-in	gray						
	7	delamination							
	8	damage							
	9	damage							

The macroscopic and microscope images in table 3 show the results of laser tempering of marksolid black colors on glass applied by screen printing. Macroscopic images of the different effects are a, c, e and b, d, f are the corresponding microscope images. Glass damage (a) with a low color residue can be observed when the laser power is too high or the scan velocity is too low. Another phenomenon, the delamination, is observed when the adhesion between glass and the color is not sufficient. Due to the scratch test also traces are clearly visible (c).

Table 3. Results of laser tempering marksolid black, applied by screen print, with CO_2 laser

	Macroscopic	Microscopic
damage	 (a)	 (b)
	f_{rep} = 20 kHz, v = 300 mm/s, h = 0.2 mm, DC = 20 %	
delamination	 (c)	 (d)
	f_{rep} = 20 kHz, v = 600 mm/s, h = 0.2 mm, DC = 4%	
burn-in	 (e)	 (f)
	f_{rep} = 30 kHz, v = 2000 mm/s, h = 0.1 mm, DC = 9%	

3.2. Laser tempering of green color

According to the results with marksolid black color, now the results with marksolid green color are shown. Burn-in of marksolid green color after laser processing is achieved with a repetition rate of 10 kHz, a low duty cycle of 6 % and a scan velocity of 700 mm/s, and a hatch of about 0.2 mm. The sample stood up to the mechanical scratch test.

3.3. Laser tempering of black color and green color

Laser parameters, which lead to a good color impression and adhesion of the colors black and green, are used to produce a two-color logo in figure 1. At first the glass was cleaned and then the color marksolid black was applied by screen printing on the glass plate. After that, the laser burn-in process of the two digits nine and six with marksolid black was performed. Water was used to clean the remaining marksolid black color from the glass. Subsequently the color marksolid green was applied to the glass and the scan velocity was increased.

Fig. 1. Combination of laser tempering the two colors marksolid black and marksolid green,
marksolid black f_{rep} = 10 kHz, DC = 6 %, v = 600 mm/s, h = 0.2 mm;
marksolid green f_{rep} = 10 kHz, DC = 6 %, v = 700 mm/s, h = 0.2 mm;

4. Conclusion and outlook

The study was conducted to use multiple colors. To conclude, the results are that the special laser colors marksolid black and marksolid green can be tempered with the CO_2 laser. A process is usually targeted at high speeds in order to achieve high process efficiency, but the burning of the color is a process which low velocities are needed. It should be noted that each color must be adjusted by other parameters in order to obtain a good coating and burn-in result. The thickness of the applied color is very important; if the thickness of the color is higher, a higher value of laser power is also necessary. For the possibility of automation and even to improve the color application on glass, in further investigations on ceramic inks with different colors will be used. Furthermore, the large-format printing and laser-burning will be examined.

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