INVESTIGATION OF HOT STAMPING PROCESS PARAMETERS IN UP&DOWN MACHINING ON ABS MATERIALS UNDER QUALITY PURPOSES OF DIFFERENT STAMPING PROCESSES

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Hot stamping foil manufacturers have been introducing only an average setting parameters gap. They are requesting that the end users find their most suitable and specific settings by changing parameters with numerous trial processes. Key parameters in machining for a hot stamping process are: die & sample temperature, dwell time and pressure; and these three variables should be proportional with each other. ABS (Acrylonitrile Butadiene Styrene) is one of the most common thermoplastic polymers in the hot stamping industry. A large quantity of identical ABS material, which is used as a water dispenser part by an international brand- Arçelik A.Ş., was ordered. In addition, this was accompanied by multiple types of hot stamping foils which are suitable for use on ABS materials. These foils have different structures and release layers and were chosen and supplied for the experiments. More than one thousand experiments were performed. The most correct parametric values were determined for each targeted pattern foils. Additional tests were performed to determine feasible end-users' harms; moreover, various failures also occurred and these failures were examined. Every result was analysed and compared with their detailed technical photos and graphs. A guide for the industry was established which would establish a new course to help machining operators reach the solution more quickly and easily, in case they have a process mistake.

Keywords: Hot Stamping Foil, Silicone Die, ABS Material.

INTRODUCTION

In the 19th century, hot stamping became a popular method of applying gold tooling or embossing in book printing (Cambras, 2004). The first patent for hot stamping was recorded in Germany by Ernst Oeser in 19th Century (Benedelk, 2010; Oeser, 1901). At the present day, hot stamping foils have been using in many industries, including (but not limited with) packaging, cosmetics, household appliances and automotive, to be applied on a material for value adding purposes. Hot stamping foil printing involves the transfer of a coating from a carrier film to the substrate to be printed by means of heated male die (Brewis and Briggs, 1985). The manufacturing of a typical foil is figured as below:

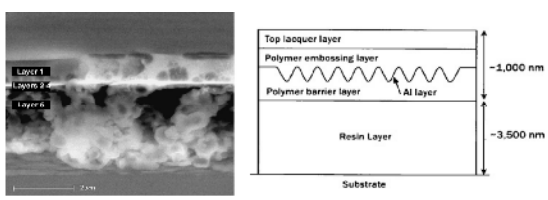

Figure 1. (a) Microtomed cross-section of hot stamping foil showing multilayer structure and (b) a schematic illustration of the layers (Leech, 2009)

Nowadays, hot stamping foil industry optionally has many different structure alternatives to be manufactured in consideration of the customer's needs and this may provide wide selection of different structures & designs for application on different type of materials. Today, it may be defined hot stamping manufacturing process in two different types (Crown Roll Leaf, Inc). In the structure, role of the layers is defined as below in Table 1. Hot stamping foil industry has a big potential in consideration of its further global market position, because it has a very wide application area for value adding by its creative design solutions and additionally allows very high durability in case the choice of foil correctly matches with type of the applied material. The most important key in this industry is to choose the correct material with the correct type of the hot stamping foil and training that matches with the correct process parameters. The present research work has been undertaken with an objective to explore correct parameters although they have been presented by their makers, with an aim of creating a guide for the operators to reach the best stamping results in machining process in case they have failure in the hot stamping process.

Table 1. Layers for Pigment Foils and Metallic Foils (Crown Roll Leaf, Inc)

Base film	Carrier film, normally PET and between 8 µm - 50 µm.
Release layer	Release the structure from the carrier film.
Protection (Colour) Layer	Protection of metallic layer. Pigment colour options.
Metallic Layer*	Brightness layer, usually Aluminium based; but may also be different such as Sn(Tin) for touch display screens or Chromium (Cr) for exterior use (e.g vehicle logos) due to its high durability.
Adhesion Layer	Adhesion on moulding, eligible by reference of the materials stamping on.

**There is no Metallic Layer for Pigment Foils.*

EXPERIMENTAL PROCEDURES

Experiments were occurred in 25 different process parameters. Matrix of experimental chart in different process parameters were formed are given in Table 2. A pneumatic Up&Down Hot Stamping Machine has been built up by a local machine maker. A large quantity of identical ABS material, which is used as a water dispenser part by an international brand-Arçelik A.Ş., two silicone dies and a workpiece sample holding fixture have been supplied by local makers of Arçelik A.Ş. A number of hot stamping foils are supplied for the experiments from an American Company - Crown Roll Leaf Inc. and from a Japanese Company-Katani Sangyo Co. Ltd. Numerous trials for each hot stamping foil have been made separately in consideration of a matrix at 2.75 bar (40 psi) including the dwell time of 0.3 sec, 0.7 sec, 1.1 sec, 1.5 sec and 2.3 sec; also including the temperature of 130°C, 150°C, 170°C, 210°C and 250°C.

Table 2. Matrix of experimental chart in different process parameters for each foil

	130°C	150°C	170°C	210°C	250°C
0.3 sec.	Trial No: 01	Trial No: 06	Trial No: 11	Trial No: 16	Trial No: 21
0.7 sec.	Trial No: 02	Trial No: 07	Trial No: 12	Trial No: 17	Trial No: 22
1.1 sec.	Trial No: 03	Trial No: 08	Trial No: 13	Trial No: 18	Trial No: 23
1.5 sec.	Trial No: 04	Trial No: 09	Trial No: 14	Trial No: 19	Trial No: 24
2.3 sec.	Trial No: 05	Trial No: 10	Trial No: 15	Trial No: 20	Trial No: 25

Figure 2. Silicone die

Figure 3. Infrared heat measurement device

Sample Preparation

Test samples were manufactured by injection moulding. The ABS samples were manufactured by using 100% ABS material. These samples are exactly the same products that has been in use in the refrigerator industry as a water dispenser part by an international brand- Arçelik A.Ş.. Silicone dies and a workpiece sample holding fixture was supplied. Silicone dies were assembled by a combination of 10mm aluminium and 2.5mm silicone; and a workpiece sample holding fixture made by aluminium only. 5-different hot stamping foil samples from an American Company - Crown Roll Leaf Inc. and 5-different hot stamping foils samples from a Japanese Company – Katani Sangyo Co. Ltd. were supplied (Table 3). The samples have technically different structures, such as thickness of the base (carrier) film (between 12 μm and 25 μm), level of the release layer (soft release and hard release), structure of protection (colour) layer and structure of metallic layer (e.g. chromium or aluminium).

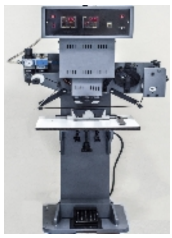

Figure 4. Hot stamping foil machine

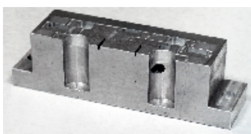

Figure 5. Workpiece sample holding fixture

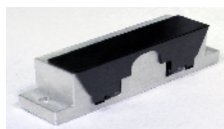

Figure 6. Workpiece sample holding fixture with the ABS sample

In the beginning, pressure of the machine's pneumatic system was set up at 2.75 bar (40psi) and the machine's heat parameter was set up at 130°C and first trial group was made in 5-steps of dwell time parameters between 0.3 secs and 2.3 secs. This changing dwell time method was repeated separately for 5-steps of heating parameters between 130° and 250°C.

Mechanical Characterization

Silicone dies and ABS samples were measured before the stamping process by using a 4-points infrared heat measurement device (Figure 3), according to compare the risk of heat change probabilities due to process speed of serial working conditions and the room temperature conditions. A decision making was done after numerous trials on different hot stamping foils and 10-hot stamping foils were chosen to include this research work. At the room temperature (for ABS samples), 25 trials were done by using each defined hot stamping foil by changing parameters on same reference values (for heating temperatures and dwell times).

Testing Procedure

Results were examined and an analysing was made after trials. The best results were chosen from the trial groups; then scratch and tape test were occurred on to examine the durability and quality of the processes.

Figure 7. One of the best stamped samples, HSF04 - Trial No: 25

Table 3. Definition of Hot Stamping Foils which had been used in the research

Foil Maker	Hot Stamping Foil Sample Number	Product Code	Carrier film thickness	Metal & Colour
Crown Roll Leaf, Inc (USA)	HSF01	BW88/260E	12 µm	Metallic Gold
	HSF02	YEA3200		Pigment Blue
	HSF03	YEA4200		Pigment Yellow
	HSF04	YEA5600		Pigment Green
	HSF05	YED6250		Pigment Pink
Katani Sangyo Co. Ltd. (JAPAN)	HSF06	CX-1001	16 µm	Metallic Silver
	HSF07	TA		Pigment White
	HSF08	HR-5431-F	25 µm	Aluminium
	HSF09	329KH718 ST NC		Tin(Sn)
	HSF10	EM-2009 Exterior		Chromium

RESULTS AND DISCUSSION

Number of hot stamping foil processes were tested (Figure 7 and Figure 8). To get more realistic and more specific results, two industrial leader companies' (from different continents) products were examined in this research. This methodology also enables to pursue a more realistic course as these two companies probably use different raw material resources due to their geographical positions. In this experiment, hot stamping foils which have exactly different structures (except YEA series of Crown Roll Leaf, Inc) were used. Pigment foils from two different series' performances proved adhesion and protection layers' importance. For instance, in comparison of YED series against YEA series, YED series have more pigment coating and it enables more covering. Moreover, metallic foils were used to prove stable quality as this is one of the most earliest established hot stamping foil types. In addition to 12 µm foils, 16 µm foils were used to examine the process difference. Although 12 µm products are usually more popular than 16 µm products in the industry, 16 µm products are also considering in case the shape of the product to make hot stamping process has a geometrically hard design with a radius. The key point is, 16 µm products has 4 µm thicker carrier film and this makes the process enable to work with higher temperature or longer dwell time and pressure in comparison to using 12 µm products. Theoretically, 16 µm products should work with higher parametric values, but in this experiment, 12 µm products needs higher temperature and dwell time. This may be explained as 16 µm products' release layer is softer level than release layer of 12 µm products.

YED series proved better condition in higher temperature than YEA series due to its higher pigment level requires higher process conditions. An interesting point occurred in comparison of YEA4200 against other two products of YEA series. YEA4200 provides its best result in lower stamping temperature and dwell time although there is no technical difference. There should be a momentary issue during the experiment while process of this product was being occurred. The measured and tested results are shown in Table 4. This is very clear that 130°C is very low for a good condition process. When the temperature reaches till 150°C, then the looking gets sharp but the quality of the stamping is not stable. Commonly, their resistance levels are low and this means the process quality still needs higher parametric values for machining settings. 170°C and 210°C are mainly preferred temperature levels for a better hot stamping process.

Table 4. Experiments' detailed test results

TRIAL NUMBER	HOT STAMPING FOIL SAMPLES									
	S 01	S 02	S 03	S 04	S 05	S 06	S 07	S 08	S 09	S 10
Trial No: 01 (130 °C vs. 0.3 sec.)	1	1	1	1	1	1	2	1	1	1
Trial No: 02 (130 °C vs. 0.7 sec.)	1	1	1	1	1	1	2	1	1	1
Trial No: 03 (130 °C vs. 1.1 sec.)	2	1	1	1	1	1	2	1	1	1
Trial No: 04 (130 °C vs. 1.5 sec.)	2	1	1	1	2	2	2	1	1	1
Trial No: 05 (130 °C vs. 2.3 sec.)	2	1	2	1	2	2	2	1	1	1
Trial No: 06 (150 °C vs. 0.3 sec.)	1	2	2	1	1	1	2	1	1	1
Trial No: 07 (150 °C vs. 0.7 sec.)	2	2	3	1	1	3	3	2	2	1
Trial No: 08 (150 °C vs. 1.1 sec.)	2	2	3	2	1	3	3	2	2	1
Trial No: 09 (150 °C vs. 1.5 sec.)	2	2	3	2	2	3	3	2	2	1
Trial No: 10 (150 °C vs. 2.3 sec.)	5	2	3	2	2	3	3	2	2	1
Trial No: 11 (170 °C vs. 0.3 sec.)	1	2	3	1	2	2	2	2	2	1
Trial No: 12 (170 °C vs. 0.7 sec.)	2	3	3	2	2	2	3	5	5	1
Trial No: 13 (170 °C vs. 1.1 sec.)	2	3	4	2	2	3	3	5	6	2
Trial No: 14 (170 °C vs. 1.5 sec.)	2	3	4	2	2	4	3	5	6	5
Trial No: 15 (170 °C vs. 2.3 sec.)	5	3	5	2	2	4	4	5	6	5
Trial No: 16 (210 °C vs. 0.3 sec.)	1	3	5	1	1	2	4	6	5	5
Trial No: 17 (210 °C vs. 0.7 sec.)	2	3	5	3	3	2	4	6	6	5
Trial No: 18 (210 °C vs. 1.1 sec.)	4	4	5	3	5	3	5	6	6	6
Trial No: 19 (210 °C vs. 1.5 sec.)	4	5	5	4	5	4	5	6	6	6
Trial No: 20 (210 °C vs. 2.3 sec.)	5	5	5	4	5	4	5	6	6	6
Trial No: 21 (250 °C vs. 0.3 sec.)	6	3	5	5	4	4	5	6	6	5
Trial No: 22 (250 °C vs. 0.7 sec.)	6	5	6	6	5	5	5	6	6	5
Trial No: 23 (250 °C vs. 1.1 sec.)	6	6	6	6	6	6	6	6	6	6
Trial No: 24 (250 °C vs. 1.5 sec.)	6	6	6	6	6	6	6	6	6	6
Trial No: 25 (250 °C vs. 2.3 sec.)	6	6	6	6	6	6	6	6	6	6
E.G. S01 -> HSF01 (BW88/260E METALLIC GOLD BY CROWN ROLL LEAF, INC)										

Point 1 - not stamped; point 2 - stamped poor; point 3- stamped good; point 4 - stamped very good; point 5 - stamped more than enough (just letter dispersing); point 6 - stamped much more than enough (dispersing)

Figure 8. One of the best stamped samples, HSF07 - Trial No: 20

Figure 9. Background of HSF01, high temp. against low temp.

Due to its carrier film, 25 μm products are designed to cover surfaces by a Roll-On type of machine, rather than Up&Down. These products may also be used under higher temperatures and longer dwell times. In this research, three different types of 25 μm products were used. Their stamping conditions were as expected, did not work well with letter stamping; but also shown that these three foils may easily work with higher temperature and dwell times and this makes the quality of stamping higher. HR-5431-F is a product with a structure of aluminum for its metallic layer. As it makes its durability higher in comparison with non-aluminum products, this is not enough strong against corrosion. EM-2009 Exterior is a product with a structure of Chromium. This product has a better durability than HR-5431-F and mainly preferred in automobile industry due to its stronger structure. 329KH718 is a semi-transparent (approx. 30% transparency) and non-conductive product, which has been used in touch screen panels due to its conductivity blocking structure, because it has Tin(Sn) on its metallic layer that makes this product non-conductive and this makes its characteristics such as a TV controller. This product is mainly used in electronics industry.

The best results of each product has been tested by using scratch and tape methods. To compare the results, 25 µm products provides the best resistances. There was no big differences between 12 µm and 16 µm products. In case of comparison between 12 µm products, YED series has better durability than YEA series.

Figure 10. Poor stamping sample, HSF03 - Trial No: 07

Figure 11. Poor stamping sample, HSF05 - Trial No: 25

CONCLUSIONS

In the present work, a number of testing was occurred and results were tested under durability issues and detailed analysing was reported. The aim of this study was to investigate the effect of parametric settings on hot stamping process and creating a guide for the industry to establish a new course to help machining operators reach the solution more quickly and easily, in case they have a process mistake. The tools used in this research work were almost the same and the results indicate the inverse relation between the stamping temperature and dwell time. With this research work, the process failures would be analysed clearly to reach the solution. This is proved that in case the pressure is stable, the temperature should be increased while the dwell time is set to be decreased for trials to gain quality. Higher temperature & increased dwell time is necessarily if the stamping is in a poor condition; and lower temperature & decreased dwell time is necessarily if the stamping quality is dispersing. The best hot stamping process must be ended with a very sharp looking, high durability against attacks and minimum touch feelings.

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