Analysis of Surface Tension of Materials to Improve Coating

Performance of Wax Coating

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ABSTRACT

The surface energy of materials used within the Investment Casting sector is currently not well understood and rarely investigated within the industry. REMET® has acquired and tested the surface tensions of binder materials and their effect on the slurry properties. Shell systems are a blend of many complex ingredients within a tank which can influence the performance of your process. In many cases, attention is paid to the plate weight and/or viscosity as a method of control for the prime slurry on a regular basis. This paper outlines the measurement of the surface tension of the binder as a method of further understanding the wetting properties of the slurry within the process. Analysis of wetting agents, concentrations and effect on the wettability of waxes is completed to understand how this parameter can affect the slurry performance.

Utilizing sessile drop testing within REMET's R&D facility, the raw materials of waxes are also being developed to better understand and increase the affinity of wax to water-based slurries to improve coating performance. Particular attention is being drawn materials to reduce hydrophobicity of wax to slurries.

Furthermore, REMET has also been investigating surface free energies of peripheral materials and their effect on the coating effectiveness. Pattern wash and release agents have~~s~~ also been investigated as these all impact the final surface area?? of materials. The results show some very interesting correlations between traditional and non-wash release agents.

INTRODUCTION

Surface tension is a key property of materials science which can influence the coating performance of materials during investment casting. REMET® UK has been investigating this phenomenon in recent years with a view to modifying this property to improve coating effectiveness between the slurry and wax during dipping.

LITERATURE REVIEW

There have been papers presented within the area of PIC into surface energies. Bozzo presented work on different surfactants in 1989 [1]. A full review of ionic and non-ionic surfactants is presented, including the difficulty in managing foam generation with the addition of surfactant. This paper outlined the materials used ever since including Victawet™ 12 and Aerosol® OT™. These products allowed a reduction in surface energy of standard DI water from 77.7 mN/mm to 34.4 mN/mm for Aerosol OT® and 31.8 mN/mm for Victawet® 12 respectively.

FOCAST mini conference within the University of Birmingham in 2002 worked briefly on the wax shell interface during de-waxing. A hot drop of wax was placed on a shell surface at different temperatures to assess the ingress into the shell [2]. This exhibited the interactions of both the permeability of the shell and molten wax during de-waxing. This paper showed that the initial wax layer penetrates the shell before it will flow from the shell as per Figure 1.

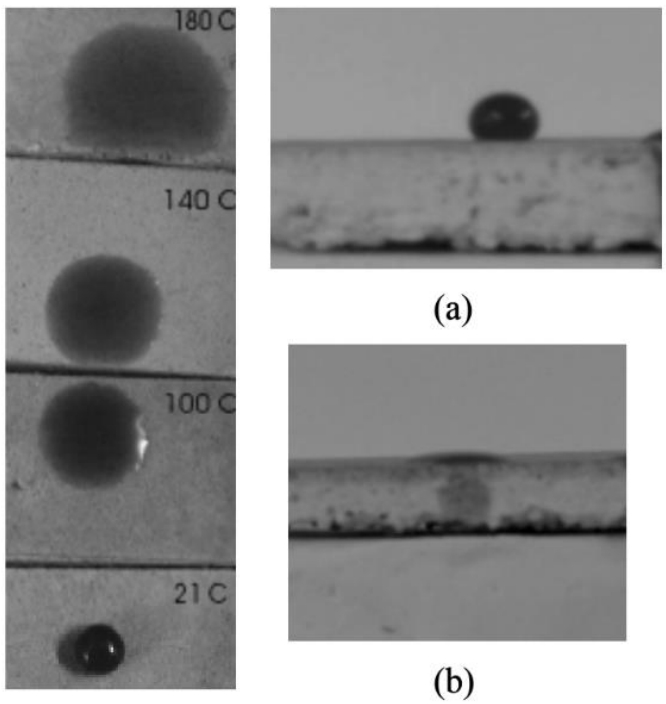


Figure 1 Wax droplet on a shell substrate at different temperatures. [2]

Finally, REMET UK presented work on surface tension in 2017 when it first acquired a Krüss® K6 Tensiometer [3]. Investigation was carried out into the effect of sol particle size on the surface tension of REMET® binders. Results showed no difference between large (10-15 nm) and small (5-8 nm) particle colloidal silicas with the presence of surfactants.

Furthermore, this work included a review of the concentrations of surfactant within a binder to achieve full wetting of the material., This work is presented in Figure 2.

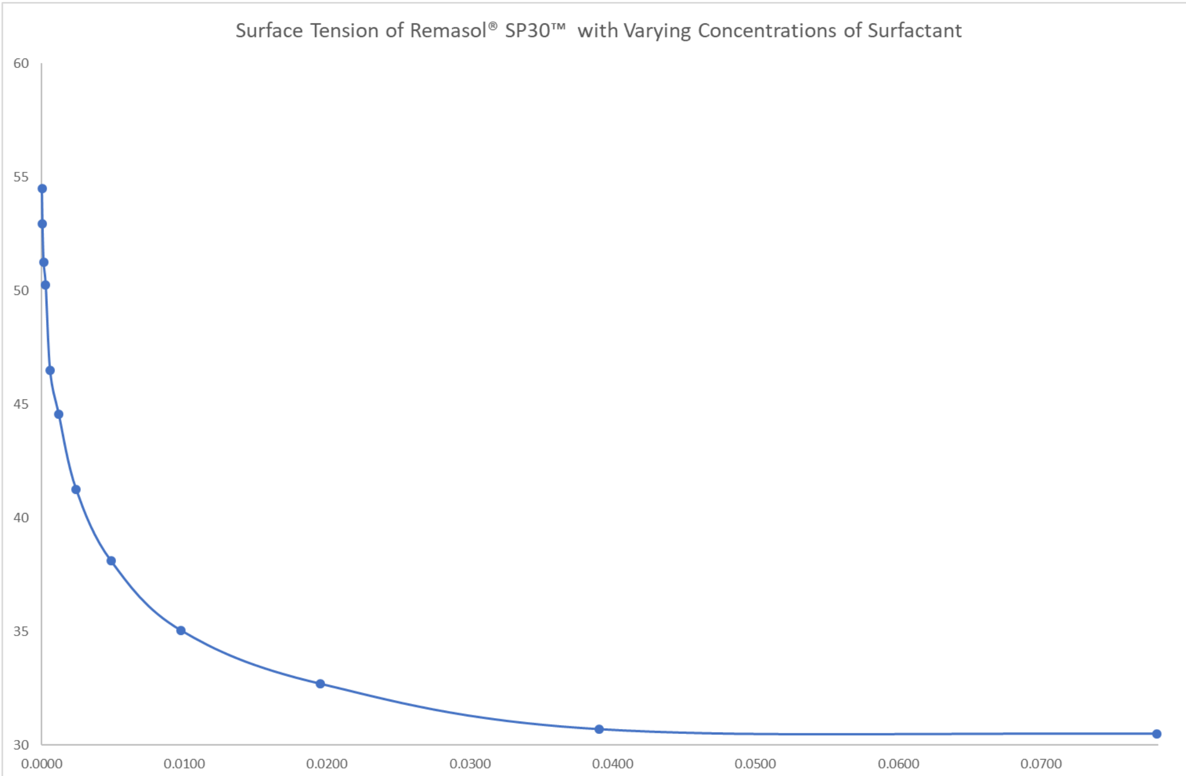


Figure 2 Surface Tension of Remasol® SP30™ with Varying Concentrations of Surfactant

Finally, the effect of these surfactants on the coating effectiveness was produced. As can be seen, the amount of material wetted onto, and retained on a surface of a metal plate for plate weight testing increases with the reduction of surface tension of the binder. These results are presented in Figure 3.

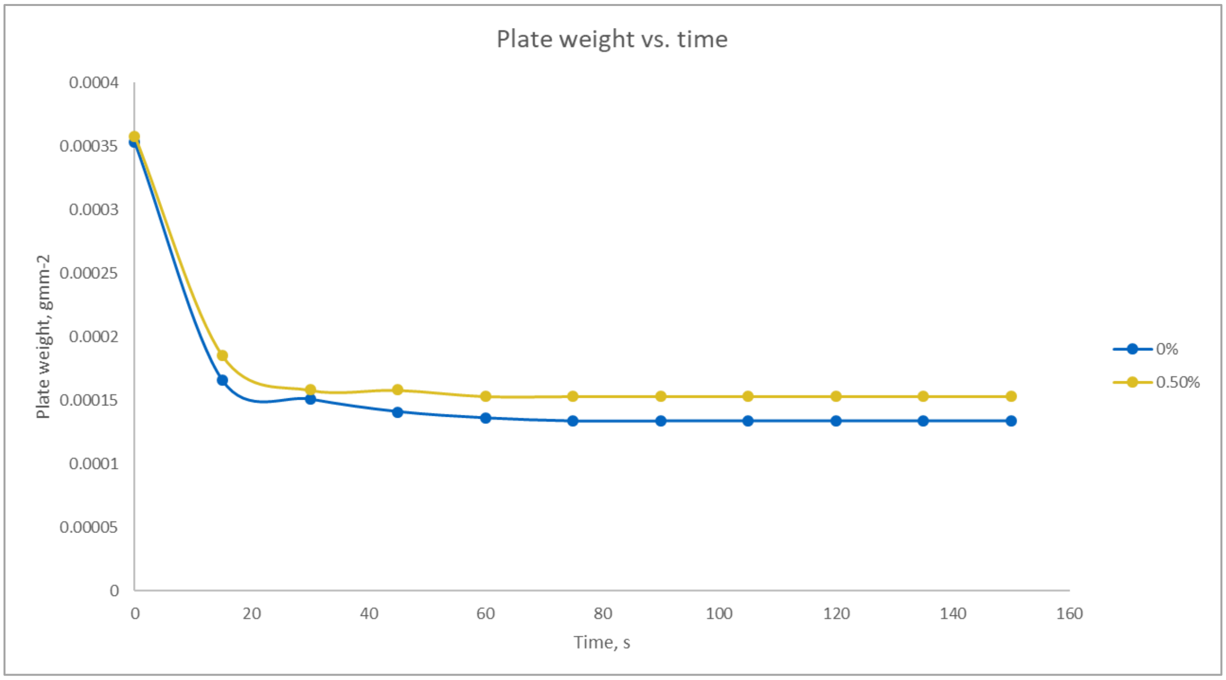


Figure 3 Effect of plate weight on slurry samples with and without surfactant

MATERIALS & METHODS

LIQUID SURFACE TENSION

A Krüss® K6™ Tensiometer was used to assess the surface tension of liquid material. This equipment utilizes the Du Noüy ring method developed in 1925 [4]. The following equation was used to calculate the surface tension.

$$\sigma = \frac{F}{\mathrm{L}.\cos\theta} \qquad \textbf{\textit{Equation 1}}$$

A platinum iridium ring was removed from the liquid and the force required to remove the ring was recorded. Due to the material used within the ring with an effective contact angle of zero, the force required to remove the ring can be directly measured as surface tension.

SURFACE FREE ENERGY

Surface free energy of solid substrates, including wax was measured using a Krüss® MSA™ (Mobile Surface Analyzer). The equipment allows for rapid measurement of surface energy by applying two drops of liquids of known surface tension onto the solid substrate. The ADVANCE™ software then analyses these surface angle of these drops and calculates the total surface energy including the dispersive and polar energies. Utilizing the sessile drop, the effect of cleaning agent and release agent was reviewed.

To first understand the coating effectiveness of two materials interacting with each other, we must first understand the material surface energies further. Materials are made up of both polar and dispersive surface energies. Polar surface energies are derived from the hydrogen bonding of atoms or molecules within the material. The dispersive surface energy is characterized by the weaker Van der Wahl's forces [5]. Many materials are made up of a mixture of these surface energies or exclusively one or the other. One example of a polar liquid is deionized water.

To calculate the interstitial energy between two surfaces, the following equation is used:

$$\sigma_{12} = \sigma_1 + \sigma_2 - 2\left(\sqrt{\sigma_1^d \sigma_2^d} + \sqrt{\sigma_1^p \sigma_2^p}\right) \qquad \textbf{\textit{Equation 2}}$$

Where *p* and *d* are the polar and dispersive energies between surfaces 1 and 2 respectively. The ideal adhesion between these surfaces occur if the interstitial energies equal zero.

SAMPLE PREPARATION

To measure the surface energy of the pattern wash, samples were poured into a rectangular mold 25 mm x 5 mm x 100 mm. These were then immersed in different pattern wash samples for 30 seconds, rinsed with water and allowed to dry.

To measure the surface energy of release agents, a 5-cavity tool was used to inject samples 25 mm x 5 mm x 250 mm. Each cavity was sprayed with different release agents for a number of injection runs and tested after a 24 hour stability period @ 25 ˚C.

RESULTS AND DISCUSSION

Firstly, we would like to understand where a standard wax surface tension lies currently within investment casting wax.

Table 1 Typical Wax Surface Energy Results

Results	Wax 2 (Unfilled)	Wax 2 (Unfilled)	Wax 3 (Filled)	Wax 4 (Filled)
Total Surface free energy [mN/mm]	22.86	22.72	21.19	27.83
Disperse [mN/mm]	22.29	22.42	20.78	27.54
Polar [mN/mm]	0.57	0.3	0.41	0.28

Based off these results, the polar surface energy of a wax is very low in comparison to the polar energy within the binder. The effect of filler on this property is also negligible. With this in mind, we can investigate the following modifications:

1. Modification of the wax recipe or raw materials
2. Pattern washing of wax
3. Modification of release agent

MODIFICATION OF THE WAX RECIPE OR RAW MATERIALS

This work concentrated on adding polar materials into waxes to increase the affinity of the wax to the binder. At present, this work has resulted in higher polarity within a wax as expected, however, it has a knock-on effect on other properties including viscosity and potentially de-wax properties.

Figure 4 shows the drop melt point of a wax which through Differential Scanning Calorimetry (DSC) testing has been proven to have the same melt point, however during drop melt point testing, the change in surface tension properties causes a shift in when the wax will flow. Linking this finding to the in the work completed by University of Birmingham [2], it is clear this may have a detrimental effect on de-waxing performance and may cause cracking.

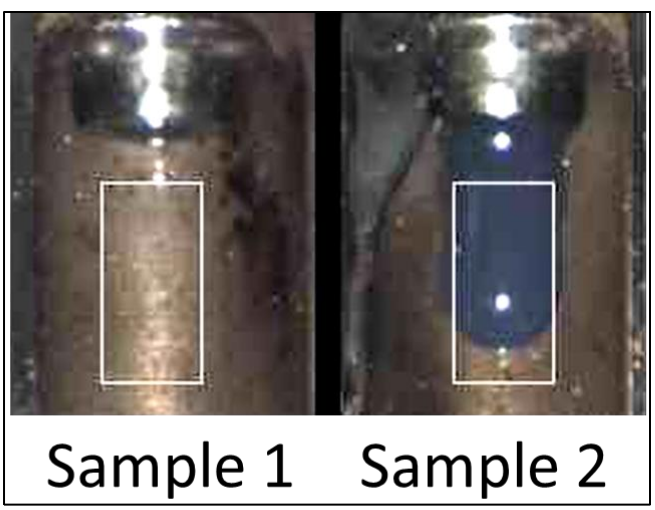


Figure 4 Effect of higher surface tension on flow and drop shape of a standard filled wax within a drop melt point tester

Pattern washing of wax

Figure 5 shows the effect of surface energy on a wax after pattern washing on the surface energy of a wax substrate.

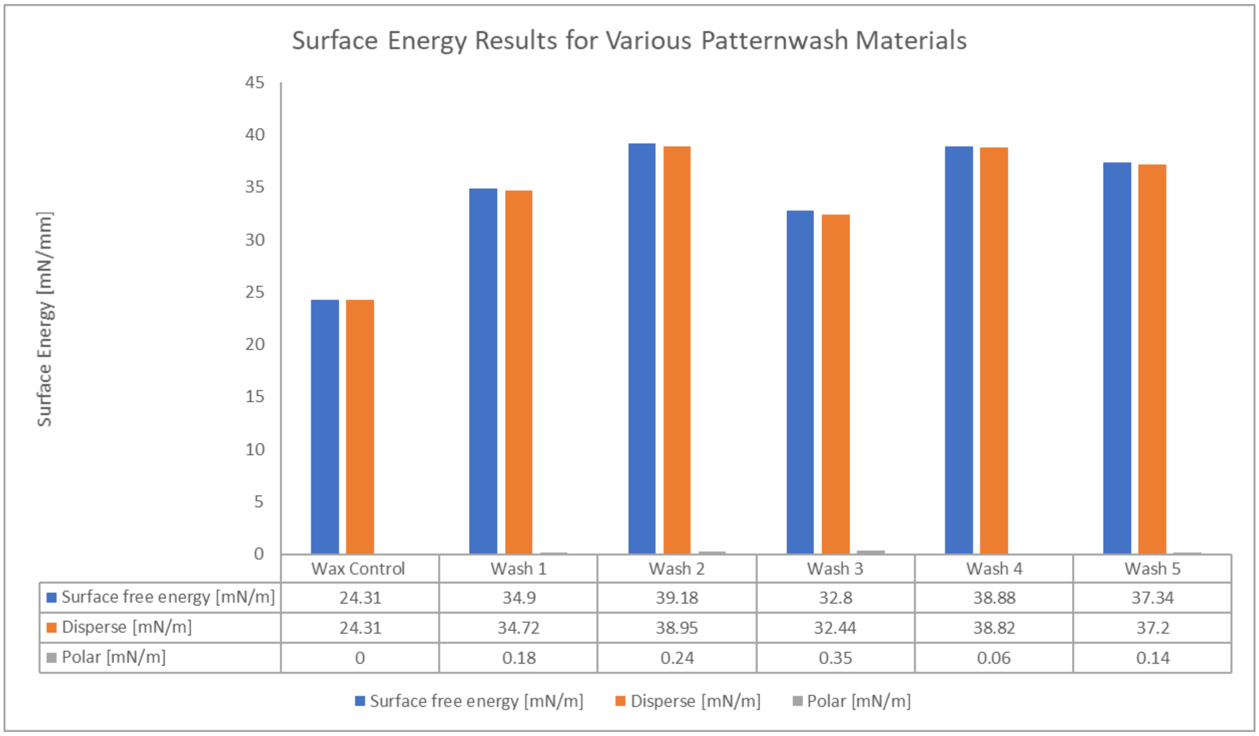
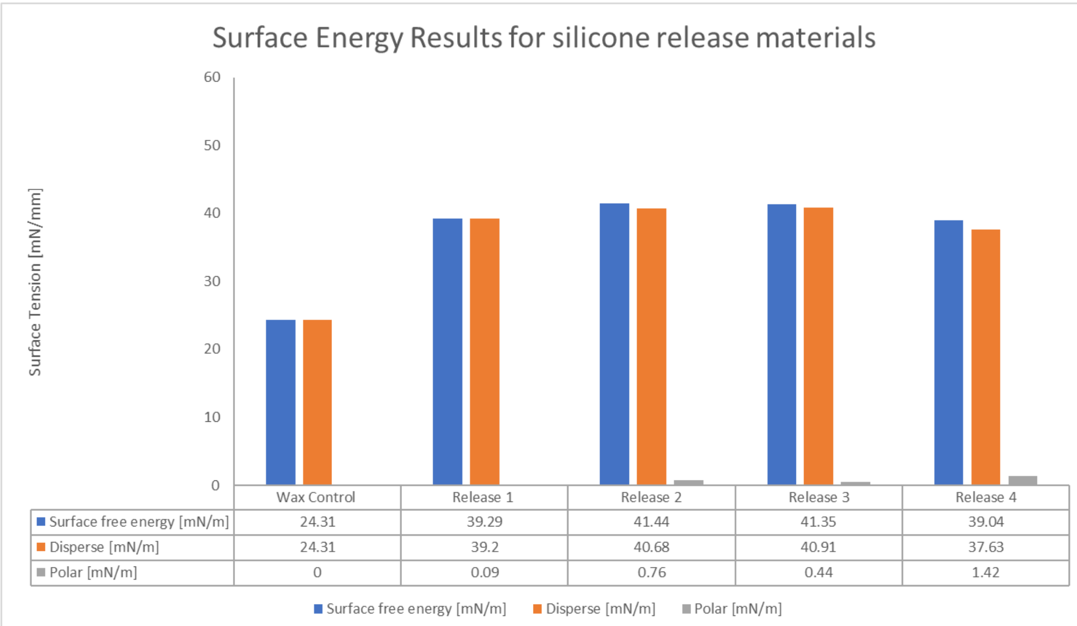


Figure 5 Surface Energy Results for Various Patternwash Materials

As can be seen, there is a change in the surface energies of the wax following washing. Predominantly, the dispersive energy on the surface of the wax increases. However, this may only be half of the story, as the surface modification may happen on a more macro level which also effects the slurry retention level. As can also be seen, the polar energy of the wax remains unchanged at near zero.

RELEASE AGENT ON WAX PARTS

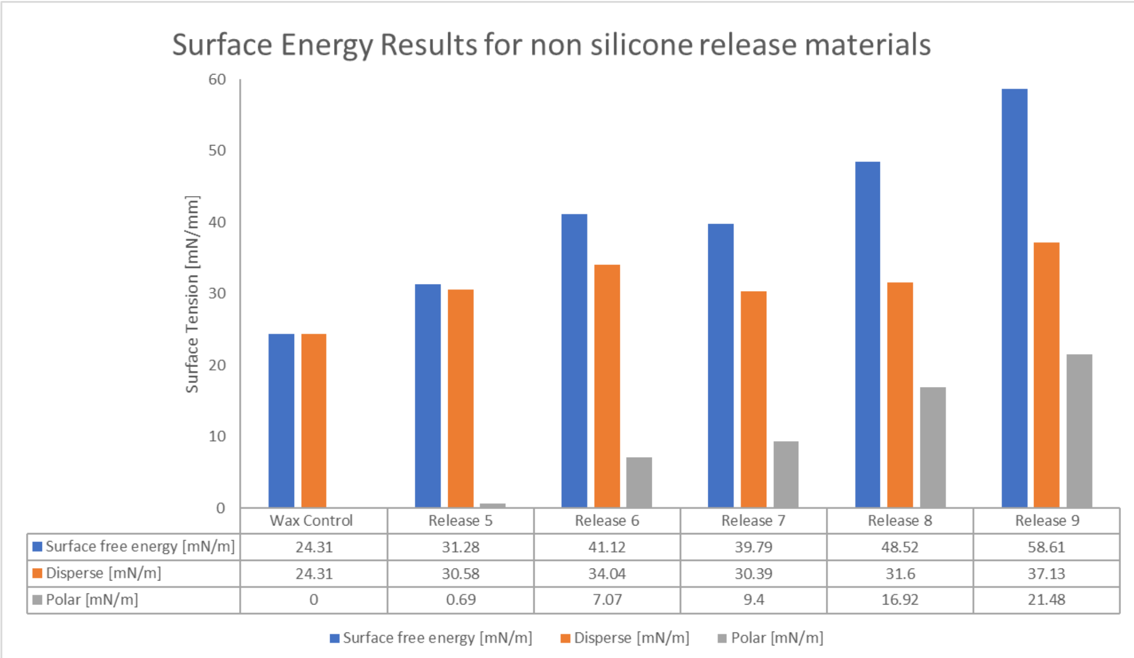
Samples 1-4 show the test results for standard silicone release agents.



	Wax Control	Release 1	Release 2	Release 3	Release 4
Surface free energy [mN/m]	24.31	39.29	41.44	41.35	39.04
Disperse [mN/m]	24.31	39.2	40.68	40.91	37.63
Polar [mN/m]	0	0.09	0.76	0.44	1.42

Figure 6 Surface Energy Results for silicone release materials

The surface energies of silicone release agent increases the overall surface tension but do little to increase the polarity of the surface, therefore this will increase the interstitial surface energies between the wax and binder material.



	Wax Control	Release 5	Release 6	Release 7	Release 8	Release 9
Surface free energy [mN/m]	24.31	31.28	41.12	39.79	48.52	58.61
Disperse [mN/m]	24.31	30.58	34.04	30.39	31.6	37.13
Polar [mN/m]	0	0.69	7.07	9.4	16.92	21.48

Figure 7 Surface Energy Results for silicone release materials

Samples 5-9 shows an increase in the polar surface energies. While samples 6 & 7 are commercially available at present within PIC market, samples 8 & 9 are new developments from REMET UK. These products offer a change to reduce the interstitial energies between wax and slurry materials. Reducing the reliance on pattern washing will increase efficiency and decrease consumable costs also.

CONCLUSION & FUTURE WORK

The low polarity surface energy of waxes is an interesting phenomenon which has not been investigated to the full extent at present. To enhance the wax/slurry wetting, the interface between wax and slurry materials can be examined in further detail including the effect of pattern wash and release agent. Future work will assess the coating effectiveness changes on the wax patterns with changing surface properties of the wax. REMET is using this technology to investigate pattern washing and release agents for next generation products.

REFERENCES

[1] Bozzo, A. (1989), “Surfactants, Wetting and Foams”, 37th Annual Technical Meeting, Investment Casting Institute.

[2] Jones, S., Jolly, M.R., (2002) BOILERCLAVE™ Thermal Profiles And The Effect Of moisture Upon Ceramic Shells During The Steam De-wax Process, 3rd FOCAST Mini-Conference, University of Birmingham.

[3] Dooley, G. (2018) “An analysis into the interaction between plate weight and viscosity for prime slurry control - What is the missing link?”, 29th EICF International Conference, Porto.

[4] du Noüy, Pierre Lecomte (1925). "An Interfacial Tensiometer for Universal Use". The Journal of General Physiology. 7 (5): 625–633. doi:10.1085/jgp.7.5.625. PMC 2140742.

[5] Dataphysics, (2019), “Dispersive & polar parts of the surface energy and surface tension”, https://www.dataphysics-instruments.com/knowledge/understanding-interfaces/dispersive-polar-parts/ . accessed 27-August-2019.