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Properties and Quality Control of Investment Casting Wax

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Blayson Olefines Ltd
Investment Casting Wax

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PROPERTIES AND QUALITY CONTROL OF INVESTMENT CASTING WAX

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Introduction

Knowledge of wax materials used must be beneficial to any investment-casting foundry. While I do not plan to unravel the secrecy of formulae etc I hope my lecture can give a view about some of the properties of casting waxes that influence pattern production and then emphasise the importance of having a quality control procedure to monitor these properties. In doing this I shall divide the lecture into the following sections: -

(1) Structure of investment casting waxes (and its influence on properties)

(2) Rough categorisation of investment casting waxes

(3) General properties of investment casting waxes (and how these can affect the quality of wax
patterns)

(4) Quality control of investment casting waxes (how properties are monitored)

Structure of investment casting waxes and its influence on properties

Modern blends of investment casting waxes are complex compounds containing numerous components such as natural hydrocarbon waxes, natural ester waxes, synthetic waxes, natural and synthetic resins, organic filler materials and water. Many variations of such compounds have been formulated to suit various requirements. Properties such as melting point, hardness, viscosity, expansion/contraction, setting rate etc are of course all influenced by the structure and the composition of any wax compound. When we are dealing with hydrocarbon waxes, natural ester, many of the synthetic waxes and a number of the resins used we are usually dealing with the compounds of straight chained carbon atoms. However, some of these resins and filler materials used could also be ring structured atoms.

For example listed in Fig, 1 are formulae for some basic components or their derivatives that can be used in certain wax blends. Generally the shorter these chains are, the lower the melting point of the waxes and the less their hardness is. With the increasing chain length, both hardness and melting point or congealing point rise. This condition that casting waxes are mixtures of a large number of components of different chain lengths or structures results in waxes manifesting a physical behaviour different from other substances.

They do not melt immediately on heating like homogeneous chemical compounds but pass through an intermediate state. To illustrate this, the graph in Fig. 2 shows hardness of a typical wax against temperature.

As seen from the shape of the curve, with the gradual heating of waxes of an initially solid consistency they become softer than plastic and with further heating semi-plastic. At higher temperatures they acquire a consistency of a thick liquid (sometimes described as semi-liquid) finally passing on complete melting into a Newtonian liquid. It is worth mentioning here that filled waxes are not true Newtonian liquids but would usually still show a behaviour similar to the depicted by the curve.

This gradual change in the overall state occurs since the short chain fractions melt first while the longer chains remain solid. With further increase in temperature the latter melt progressively until the liquid state is reached. The actual shape of the curve and the temperature range of each phase is naturally a reflection of the specific make up of the blend.

Of course on cooling the reverse process takes place. It occurs, according to the type of wax blend, over a longer or shorter temperature range and therefore we can have a range of pattern waxes with slow to rapid setting rates. It is this succession of states that renders wax particularly suitable for the injection process. It behaves in a similar way to the majority of plastics except that their liquification and processing temperatures are located far higher.

The length of the carbon atom chains and hence wax structure also affects viscosity of the casting wax. Basically the property of viscosity of a wax is best illustrated by showing a series of typical viscosity curves and relating viscosity to the setting rate or cooling range of a wax as in Fig. 3.

Waxes expand like other materials under the influence of heat and when they cool they contract. In comparison with a metal the expansion of a wax is relatively high. In waxes the expansion and contraction rates over the rough range between 20°C and melting point are not uniform per degree centigrade but change in the temperature range as a function of their structure. It may be useful to demonstrate this by showing the typical expansion curves for three materials as in Fig. 4.

A) An homogeneous crystalline organic substance
B) A wax

(A)
The crystalline substance behaves like any solid and undergoes relatively little expansion. At melting point the crystalline structure suddenly breaks down and a sudden transition into the liquid state occurs which is characterised by a sudden in expansion. In the liquid state the expansion is again small.

(B)
In wax the short chain fractions become soft even at low temperature giving a gradual rise in the expansion curve. In the case of the higher molecular wight, crystalline fractions, the curve assumes a steeper increase and then rises slowly again on the transition to the liquid state.

(C)
Amorphous resin behaves differently. It has a uniform pattern of expansion from the start of heating to the liquid state, no sharp increase in expansion occurs, since no crystalline elements are present. Hence the addition of certain resins to waxes can reduce the crystalline structure of the waxes and thus also reduce their expansion/contraction capacity.

In this brief look at structure we have a simplified view of how or why numerous components are added to a wax blend and the properties that result. We can now move on to consider the types of waxes used and general properties of these.

Rough categorisation of investment casting waxes

For ease of reference casting waxes can be divided into the following rough categories as shown in Fig. 5.

a) Pattern waxes

b) Runner waxes

c) Water soluble waxes

d) Other special waxes such as dipping, patching and adhesive waxes. Pattern waxes can be further categorised into the following three main areas: -

1. Straight or unfilled pattern waxes
2. Emulsified pattern waxes
3. Filled pattern waxes

Straight or unfilled pattern waxes

These are in effect complex compounds of many waxes and resins. When using a straight wax there is sometimes a greater tendency for cavitation to occur. However with the use of chills to overcome this cavitation on any heavy sections they are used by numerous foundries. The surface finish of straight waxes would normally be shiny and of course reclaiming is straightforward for runners or patterns.

Emulsified pattern waxes

These have similar base materials to the straight waxes but are emulsified with water normally between 7 – 12%. The surface finish is extremely smooth and because the water acts partially as a filler less cavitation takes place. Handling of emulsified waxes is quite simple providing the foundry keeps to the guidelines laid down by the supplier. They have become extensively used due to their versatility and ease of reclaiming for runners or patterns.

Filled pattern waxes

Here again the base materials are similar to those of the other two categories but into the compound is blended a powdered filler material, insoluble in the base wax, to give the compound greater stability and less cavitation. It is essential that the filler used is organic to ensure complete burnout leaving no ash and there are a number of different filler materials used. It is also critical to use a fine particle sized filler as near as possible to the base wax to ensure minimum separation takes place when the wax is liquid. Here again they are widely used but reclaiming is normally only for runner systems. Now let's move on to look at the general properties that influence investment casting waxes.

General properties of investment casting waxes (and how these can affect the quality of wax patterns)

As explained before the majority of investment casting waxes are complex compounds of numerous components. Each component has been included to influence the final properties of the compound in some way. These properties of the wax are obviously of critical importance to the foundry in the production of good castings. Once a specification for a casting wax has been agreed between wax manufacturer and foundry it is essential that the material is manufactured, tested and supplied within these limits.

In looking at general properties of casting waxes it may be useful to do this by considering a series of points that affect the quality of casting wax and hence pattern production. These are listed in Fig. 6.

1) Contraction and cavitation
2) Congealing point or melting point
3) Ash content
4) Hardness and elasticity
5) Viscosity
6) Good surface finish
7) Setting rate
8) Oxidation stability
9) Reclaimability
10) Any others

(1)
Stable results on contraction and cavitation of a casting wax are of course extremely important to the foundry. Once a foundry has decided on a particular wax compound it is essential that the contraction/cavitation rate is maintained. We have already discussed how structure can affect contraction emphasising that certain components of the compound will influence the property highlighting the importance of both the wax manufacturer's and foundry's quality control tests. It is worth mentioning that

although stability of contraction rate of the wax is critical, it does not mean the foundry cannot change waxes. With a better understanding of materials and a close liaison between foundry and supplier this can be achieved. It is possible for the supplier to develop wax compounds with a foundry's specific requirements in mind and in the majority of cases submit a wax that meets these requirements providing such requirements are not too demanding.

(2)
Again we have considered how structure influences the congealing point or melting point of a casting wax. These in turn have a major influence on the required injection temperature of the wax. As was explained in the section on structure of waxes, casting wax passes through a number of phases on heating and/or cooling. Congealing point and melting point will represent temperatures at the beginning and end of the semi-liquid state respectively. With the knowledge of either temperature the correct wax conditioning and injection machine temperatures can be set.

(3)
Most foundries would be aware of the importance of using and maintaining a wax with a low ash content and of the detrimental effect of ash. The limit recommended by BICTA is 0.05% maximum. However it is also important not to place all the emphasis on the percentage weight of ash without considering the nature of residue left and whether this could cause problems in the mould and affect the resultant casting.

(4)
We have discussed how structure can affect hardness of a wax. It is necessary that the wax has sufficient hardness and elasticity to help reduce the possibility of rejects due to breakages, bending or other undesirable phenomena during the subsequent processing of the wax pattern. Different components will affect the wax compound in different ways.

(5)
Again we looked how structure influences viscosity of wax. The viscosity of a casting wax compound is critical to successful pattern production. Where large fine sections need to be produced then often a low viscosity wax is required to enable the wax to penetrate into the finest spaces in the die. For heavier sections a less fluid wax may be preferred. If a wax with the incorrect viscosity was used for a particular application then the flowability of the wax into the die will be wrong. This can only highlight how critical the property viscosity is and why quality control is necessary in this area.

(6)
Again good surface finish is an important property for successful pattern production. It almost goes without saying that a poor quality wax pattern surface will give the same poor quality to the resultant casting. The three major categories of pattern wax; straight, emulsified or filled will give, as mentioned earlier, different surface finishes. In general straight waxes are shinier on the surface; emulsified waxes are smoother on the surface, whereas filled waxes have a slightly rougher surface. In their own way all three are satisfactory and foundries have their own preferences.

Examples of the types of surfaces that could prove detrimental are the ‘soft easily damaged’ surface or the ‘pitted’ surface usually associated with coarse particle sized filler being used.

(7)
The foundry must have knowledge of the setting rate of a wax in order to successfully produce wax patterns and we discussed how different structures or components give different setting rates. On one extreme, foundries are producing parts where they require a very fast set and release from the die. Whereas on the other extreme, a slower wax is an advantage.

(8)
Stability of the wax compound is a further property worth consideration. Here one is thinking in terms of the ability of the compound to resist oxidation or breakdown of certain of its components due to the action of heat or simply ageing. Some components have a greater tendency to oxidise than others and it is necessary for the manufacturer to antioxidant materials where this could occur. If oxidation of the wax does occur then the overall properties will markedly change and the compound may be unsuitable for use. The reclaimability of a wax when in the autoclaved state is an important area of consideration, not only ecologically but also economically.

(9)
The method of reclamation used would be similar for all three major categories of pattern waxes mentioned previously with some slight variations, but the most important aspect for foundries to consider regarding reclaiming, is that they decide to use the reclaim wax for – runner bars or both runner bars and patterns. While stating it is possible to reclaim all three categories of wax, strict quality control over the process is recommended. If this is carried out then reclaim material can be widely used. One major example is to check the ash content of the reclaimed material and to look at ways on how this can be reduced further. It is advisable to ensure, that only one grade of wax, patterned and reclaim runner, is run out of the autoclave to avoid unnecessary contamination. It is also important to minimise contact with metal oxides (corroded parts), which cause metal to combine in solution with the wax, giving high ash content. It is important to test the penetration (hardness) of the reclaimed wax. Autoclaving and hence heating of wax causes a breakdown in structure of the compound, often giving a change in properties. For example, the reclaim wax could become more brittle and more susceptible to dimensional variation. The need for these tests simply highlights the importance of a quality control system.

(10)
No doubt there are other properties that could be considered. For example, the fact that such compounds should be non-toxic is obvious. Also we have not discussed water soluble waxes where properties are somewhat different and those would need to be discussed in a separate paper.

However the items considered in 1 – 9 should cover the majority of general properties of investment casting waxes and how these can affect the quality of a wax and wax pattern production. We can now consider quality control and some of the tests available for testing of waxes and for ensuring the properties and specifications of waxes are maintained.

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Quality control of investment casting waxes (how properties are monitored)

As the industry has become more sophisticated so the importance of quality control of all materials has grown. In the previous section the properties of waxes and their importance to wax pattern production was discussed. Now we can say it is equally important to monitor these properties by both manufacturer and foundry using a strict quality control procedure. For the foundry it ensures that the material purchased is within the specification issued or agreed with the manufacturer and will therefore produce patterns equally as good as those produced from the previous batch of material supplied. For the manufacturer, it will ensure that the material is within specification and the correct components have been blended.

There is currently a growing emphasis on the quality system BS5750. At Blayson Olefines we are implementing the system. Certainly with such systems it puts quality control on a much higher level and aims to ensure all products meet the necessary specification.

When a foundry produces wax patterns it will usually do so against set machine and die parameters for specific patterns.

E.g. Wax temperature injection machine
Nozzle temperature
Die and/or platen temperature
Injection pressure
Flow control
Injection and hold time etc

If there is a variation in material specification, such as congealing point, penetration or viscosity and the customer has not been informed, then a considerable amount of time can be wasted producing reject patterns before the machine variables are adjusted satisfactorily.

Most associations/institutes would issue their own recommended test methods. They are sometimes varied by individual manufacturing companies, but as long as customer and manufacturer are looking at the same test methods, this is not critical.

The tests recommended by BICTA are listed in Fig. 7.

1) Melting point (drop point)
2) Congealing point
3) Ash content
4) Penetration
5) Viscosity

Melting point (drop point) and Congealing point

The definition of the melting point is: -

"The melting point is the temperature at which a drop of the sample detaches itself from the main bulk."

As the melting point is closely allied to the congealing point test we can deal with them together, but first the definition: -

"Congealing point is that temperature at which molten wax, when allowed to cool under prescribed conditions, ceases to flow."

The results give a variation in temperature but for practical purposes they give a picture of what is happening to the compound. Most important is that for the customer it gives a guide to temperatures required in the injection machine tank and the injection temperature itself whereas for the manufacturer it is a further check on materials used.

Ash content

No definition is required for ash content as this is self explanatory. It represents the percentage of non-combustible solids contained in the compound and providing the figure is below the required limit, it is accepted by the customer and manufacturer.

Penetration

Penetration is defined as: -

"The penetration of a wax compound is the distance in tenths of a millimetre that a standard needle penetrates vertically into a sample of the material under fixed condition of loading, time and temperature."

Penetration of course gives the customer a guide to the hardness of the wax. If the penetration figure has increased but is still within the limit, then the compound is slightly softer, and it may be necessary to increase the hold time in the die to maintain dimensions. If the penetration has decreased then the converse applies. For the manufacturer the test is again a further check on materials used.

Viscosity

The definitions of kinematic and dynamic viscosity are given as follows: -

"Kinematic viscosity is a measure of time for a fixed volume of liquid to flow through a capillary. The unit of KV is the Stokes, which has the dimension centimetres squared per second.
In the petroleum industry, kinematic viscosity is usually expressed in Centistoke (cSt) so that
1 St = 100 cSt."

"Dynamic viscosity is numerically the product of kinematic viscosity and the density of the liquid, both at the same temperature. The unit of dynamic viscosity is the poise – P, which has dimensions grams (1) per centimetre per second."

For Newtonian fluids, the absolute (dynamic) viscosity is defined as "quantitative measure of the Tendency of a fluid to resist sheer."

The results of these tests give the customer a guide to the flowability of the wax, the pressures required to transfer wax from machine to die and the size of the injection channel required to maintain pressure applied. Again for the manufacturer there are further checks on materials used and the general properties of the wax.

Finally, there are a number of other tests sometimes applied to a wax. These include dimensional, volumetric contraction/expansion, linear contraction/expansion, strength, specific gravity etc.

Conclusion

What I have tried to do in the lecture is indicate that investment casting waxes are compounds of many different components and show numerous different properties. Most of these properties have an effect on how the wax behaves. As the industry progresses it is very important that strict quality control is applied so as to monitor such compounds in order to achieve successful wax pattern production and to increase one's understanding of waxes.

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