INVESTMENT CASTING WAXES :
INFLUENCES WHICH ELIMINATE WAX PATTERN DEFECTS

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INTRODUCTION

The way pattern wax is handled during the melting, conditioning and injection stages of pre-pattern production will directly reflect the quality of wax patterns produced in the wax room. Proper handling methods can eliminate a multitude of wax pattern defects for the investment casting foundries. It is important to recognize that all of the materials used to produce a casting are part of a **system** and must work together to make a quality casting. Therefore, the final casting can only be as good as the wax patterns produced.

Pattern Wax Composition

Pattern waxes are blends consisting of components such as:

- Petroleum waxes
- Natural waxes
- Natural and synthetic resins
- Organic fillers

Paraffin and microcystalline waxes are both produced as by products of the distillation of crude oil. Paraffin is the most commonly used of the petroleum waxes because it is less expensive compared to other raw materials. Paraffin wax also controls or enhances the rheological properties, which in turn affect the injection temperature and fluidity of the pattern wax blend. Paraffin wax is available at multitude of melting points.

Microcrystalline wax is available at various melt points and hardnesses. Two microcrystalline waxes from different suppliers that have identical melt points are not likely to possess the same properties because the oil content and processing methods may vary. Microcrystalline wax gives some control to the flow, hardness and strength of the pattern wax. A blend of paraffin and microcrystalline wax would make a pattern which lacks cohesiveness. Resins are added to the blend to increase body and strength.

Resins are derived from natural sources such as pine trees, crude oil, and coal tar. Some resins are also produced synthetically. Resins are used in the formulation to add body and may affect solidification, shrinkage, rigidity, hardness, and tackiness of the wax blend. They are produced in a variety of melting points, hardness and crystallinities.

Additional additives include carnauba and candelilla waxes. These natural waxes are derived from leaves and tree shrubs in Brazil and Mexico. Natural waxes affect the hardness, surface finish and set up properties of the wax blend. There are synthetic additives used in wax formulations such as polyethylene resins. The qualities of synthetic products tend to be more reliable and stable compared to those products from natural raw materials.

The introduction of organic fillers has become an important development in the formulation of investment casting waxes. The selection criteria for fillers are:

- Organic
- Low ash content
- Relatively high melt point
- Non-reactive towards the base wax – ceramic and metallurgical processes
- Fine particle size distribution
- Specific gravity close to the base wax.

The most commonly used fillers are:

- Isopthalic Acid
- Polystyrene (Thermosetting & Thermoplastic)
- Bisphenol A
- Hydro-Fill.

Soluble Wax

Most soluble waxes are comprised of (3) three raw materials:

1) Binder
2) Filler
3) Effervescing carbonate.

The binder is polyethylene glycol commonly known as PEG. PEG is available in numerous molecular weights and is used in various combinations to achieve the desired viscosity, hardness and melt point characteristics. The filler consists of a fine powder material that is primarily used to improve shrinkage characteristics. It also helps the overall structural strength of the blend. Fibrous materials are used to improve the strength and the elastic properties of the wax. Sodium Bicarbonate is the effervescing agent in the wax that helps break down the soluble wax during the leaching process. This material also acts as a bulking agent. The fillers and sodium bicarbonate are inorganic materials. The inorganic characteristics of soluble waxes make it necessary for foundries to adhere to the recommended handling procedures. These procedures include: proper heating, agitation and segregation of patterns from non-soluble wax materials.

Various combinations of raw materials are used to impart characteristics to the wax formula. This will result in a pattern wax that is best suited for the individual needs of the investment casting foundry. Important properties to be considered during the development of investment casting waxes are:

Ash Content
Hardness
Viscosity
Ductility
Surface Tension
Wetability of Primary Coat
Volumetric Expansion
Surface Smoothness
Melt point
Shrinkage, Cavitation or Sink.
Thermal conductivity

In addition, all of these ingredients must work synergistically to provide a pattern wax that is user friendly in all aspects of the process and which cover the entire spectrum of refractories to alloys.

Wax Preparation

The method in which pattern wax is handled during the melting, conditioning and injection stages of prepattern production will directly reflect the quality of wax patterns produced in the wax room. Pattern wax is the starting point of production for investment castings. Therefore, "your final casting can only be as good as your wax patterns produced".

Melting

Overheating can oxidize some of the raw materials and may cause the wax to become too brittle or rubbery depending upon the formulation. There are some fillers that are temperature sensitive when overheated. The filler can separate from the base wax and can cause dimensional variation, poor flow and surface defects.
Standard meltdown temperature for filled and unfilled waxes when using a cylindrical melt tank is typically between 180-200°F. Some temperature sensitive fillers should not exceed 180°F. It is recommended that a slow speed stirrer always be used while the wax is in its molten state. This is an absolute necessity when melting filled waxes and highly recommended for unfilled waxes. Agitation will help prevent localized overheating and settling of the filler material.

Plate type melt units are designed to melt wax on a continual basis. These box design units will provide liquid wax directly into the conditioning tank or wax reservoir on demand. Hot air or a hot plate heats the solid wax. The hot plate should be at a sloped angle and have a high temperature limit / cutoff. This will prevent the wax from overheating and the fillers from settling out of the base wax. The set point temperatures for these units are usually higher in comparison to the cylindrical melt tanks. This is because the wax does not situate itself on the sloping hot plate long enough to reach the maximum set point temperature. Recommended set point temperatures for most pattern waxes is between 210-240°F.

Soluble wax meltdown temperature is between 185-195°F. The temperature should not exceed 210°F since certain raw materials will break down. When soluble wax fillers decompose the material cannot be used. The soluble wax should then be discarded from the tank. Soluble pattern waxes contain a considerable amount of high-density inert fillers. Constant agitation of the wax is recommended during meltdown through injection. Soluble filler separation effects surface finish, strength, dimensions, and decreases the leaching rate.

If there are any questions concerning which melting procedures should be used, consult with the wax manufacturer for proper operating parameters.

Conditioning

Most waxes are injected below their melting point and sometimes well below the melting point of the components. To insure uniformity, it is best to temper the wax by holding it close to its injection temperature for a few hours before use. This should be done in such a way that air is not entrapped into the wax mixture. Once air is entrapped at or near injection temperature, it is very difficult to remove the air because of the high viscosity of the material. The wax temperature must be raised in order to lower the viscosity of the blend, thus allowing the air to escape.

Wax should not be directly transferred out of a melt tank which is at temperatures of 180-210° F and then poured into an injection press that is set between 150°F or lower and expect to inject quality patterns. If the wax is handled in this manner; most likely the actual injection temperature at the nozzle is higher than the established parameter or limit. The daily routine for wax rooms to follow, if they are not using a central distribution system is to fill wax machines when they are approximately one-third empty. This will allow hotter wax to mix with cooler wax in the machine and come to equilibrium faster. It is advised not to wait until the machine is completely empty before filling the reservoir. You will be injecting hot wax and a substantial amount of air will be entrapped in the reservoir. Wax is a poor conductor of heat. It takes a considerable amount of time to melt and it will take a fair amount of time to lose its' heat.

If properly conditioned the viscosity, flow and surface finish will benefit most by this procedure.

INJECTION CHARACTERISTICS

Pattern materials are usually designed for operation in either liquid or semi-sold injection machines. For clarification the term liquid refers to those materials which can be poured. Semi-solid are those materials that cannot be poured and require pressure to move them.

Semi-solid pattern materials are usually injected at lower temperatures and higher pressures than liquid pattern materials. The benefits are less dwell time and less cavitation in heavier sections. The semi-solid material is about 75% through its plastic range when it is injected whereas; the liquid material has to go through its plastic range from injection to its set up time. There is a greater tolerance of temperature variation in semi-solid injection equipment. The semi-solids create fewer problems in daily use as their longer plastic range flow characteristics provide an almost self-regulating control over the rate of injection and speed in which they fill the mold. This allows for ideal filling of the mold, first at the nozzle, then progressively to the farthest point of the mold acting as a high surface tension hydraulic piston moving air and leveling nodules of lubricant ahead of it.

Liquid components have shorter plastic ranges. Since liquid materials have lower viscosities and lower surface tensions, it is important to control the speed of the wax during injection for ideal mold filling. Liquid pattern materials are more prone to air inclusions and turbulence during injection.

- Viscosity curve showing zones for billet, paste and liquid –Insert A

INFLUENCES

Mold Filling and Temperature

If slow injection is used more time is available during the injection shot for the material entering the mold to cool and increase in viscosity. This condition will generally require a higher pressure to fill the mold because of the increased resistance to flow due to the stiffening of the material. When a fast fill is used, the material fills the mold so quickly that a minimal amount of temperature change takes place in the shot. At the lower average viscosity of the mold, less pressure is required. The rate of pressure drop depends on the speed of set and the fluidity of the wax. Initial pressure must be high enough to be maintained to the most distant pattern section.

The mold temperature will also influence the pressure required to fill a mold at a given injection pressure in pattern material. If the mold temperature is too low, the material may freeze and stop the flow of the material into the mold before it is completely filled. Running the mold too hot will require an excessively long dwell to the part where it is sufficiently rigid to move or it will cause flash. Slow setting fluid waxes require colder molds than fast setting waxes. Rapid chilling of the tool yields an irregular pebbled surface. A warmer mold is recommended for fast setting waxes. With a fast setting wax it is best to run the mold at a warmer temperature as opposed to raising the wax temperature.

Sprue Size

The wax flow and pressure exerted must be transmitted through the feed. It is best to make the feed/sprue as large as possible. A small diameter sprue chills rapidly especially with a fast setting wax, resulting in decreased flow, non-fill and increased cavitation. If pressure is to be exerted during injection the wax must remain plastic enough in order for the pressure to be transmitted through the pattern section.

Wax Temperature

Proper preparation of the wax prior to injection will eliminate a multitude of pattern defects. Wax works best if it is held within a narrow temperature range. Injecting wax 5°F higher than a recommended injection temperature can cause poor flats on the pattern. Hotter wax will give a better surface but will cause other problems such as:

- Dimensional changes
- Excess cavitation or sink
- Excess flash on wax patterns
- Shrink voids or undersized patterns
- Increased dwell times
- Air entrapment due to turbulence in the die

Pattern waxes have a melting point as well as a solidification point The solidification point can be as much as 30°F below the melting point with the injection temperature somewhere in between. Inferior temperature controls or carelessness can allow the wax temperature to drop too low. Injecting cold wax include:

- Wax non-fill
- Ripple and knit lines
- Dimensional change
- Surface defects (example: graininess or orange peel effect)

If the wax becomes too cold, raising the wax temperature a few degrees may not cure the problem. There are high melt point constituents in wax formulas that crystallize once they are held below their solidification temperature. By only raising the wax temperature slightly, these hardened crystals do not soften enough to fully blend back into the pattern wax formula. The best solution is to raise the temperature above the melting point of the wax. This will liquify the high melt point components and allow the blend to become thoroughly homogenized back to its original state. The temperature can then be lowered to the recommended injection temperature. Checking the temperature gauges and actual wax temperature at the nozzle should be part of the daily quality control routine in the wax room.

Die Design

Sprues should be as large as possible preferably 1/2" to 5/8" diameter. The distance of the sprue (nozzle feed) should be as short as possible. This will prevent chilling of the wax during injection.

Sprues should inject wax into gates at the heaviest area of the casting. This will eliminate the need for patching when sprue is removed from the pattern.

Cooling water jackets in dies are recommended for heavy section patterns.

Insulated sprues are recommended to reduce cavitation in heavy section patterns. The wax remains fluid and will feed the pattern during the dwell time.

Metal dies produce the best quality patterns because heat transfer is better than polymer dies.

The injector nozzle should have nylon, urethane or Teflon insulating tips to prevent chilling of the nozzle or excessively heating the die.

STRESSES

Stresses can be set up in wax patterns by unequal rates of cooling, causing unequal contraction. Stresses show up as warpage of the pattern. Lower injection temperature, longer dwell, and sometimes outside cooling reduce the amount of stress which in turn reduces the warpage of the pattern.

SUMMARY

Pattern materials are the initial starting point in the investment casting process. Mishandling of these materials can result in added costs to the final casting. Proper care and handling of these materials will result in a cost savings to your company.

COMMON WAX PATTERN DEFECTS

1) Non –Fill
2) Flow Lines & Knit Lines
3) Poor Surface
4) Flash
5) Soluble core breakage – defects
6) Air Bubbles
7) Wax pattern cracking
8) Sink , Cavitation & Shrinkage

PATTERN DEFECTS : CAUSE AND CORRECTIVE ACTION

1) NON-FILL

CAUSE	CORRECTIVE ACTION
Improper mold venting	Clean vents and cores Enlarge vents if possible Use less mold release
Adjust flow rate	Decrease or Increase flow rate
Cold Die	Adjust Platen temperature
Excessive mold release	Clean tool and re-spray
Size of injection sprue	Resize injection sprue
Cold nozzle-wax slug	Adjust nozzle temperature Change tips to NonInsulating
Trapped air in die	Change fill pattern -reverse tool.
Pressure	Adjust pressure

2) FLOW LINES, KNIT LINES

CAUSE	CORRECTIVE ACTION
Cold wax	Adjust Temperature
Hot wax	Adjust Temperature-or flow control Hot wax causing turbulence
Mold Venting	Clean vents and cores Add or enlarge vents
Excess mold release	Decrease mold release Mold release will travel in front of the wax upon injection which will prevent wax from fusing together
Cold die	Adjust platen temperature or preheat die
Sprue design	Enlarge sprue or change location of
Wax flow	Adjust flow rate
Low injection pressure	Increase injection pressure

PATTERN DEFECTS : CAUSE AND CORRECTIVE ACTION

3) POOR SURFACE

CAUSE	CORRECTIVE ACTION
Wax Temperature	Adjust Temperature
Filler Separation	Check bottom of tanks for filler Add or increase agitation
Improper wax conditioning or meltdown	Check wax handling procedures (Melting through Injection)
Wax flow	Adjust flow rate
Low nozzle Temperature	Increase nozzle temperature
Overheating of wax	Overheating can cause defects.
Low injection pressure	Increase pressure
Low Nozzle Temperature	Increase Temperature - most common with Billets

4) FLASH

CAUSE	CORRECTIVE ACTION
Low clamp pressure	Increase clamp pressure
Unequal clamp pressure	Check clamp and guide pins for correct placement
Die not closed properly	Check guide pins
Die wear	Check for rounded corners on parting lines
High injection pressure	Decrease injection pressure

PATTERN DEFECTS : CAUSE AND CORRECTIVE ACTION

5) SOLUBLE CORE BREAKAGE

CAUSE	CORRECTIVE ACTION
Core fit print	Place soluble in tool, clamp tool and open tool to check for damage Check warpage of soluble core Check parting line and/or alignment on core seat Provide supplementary pin supports
Injection parameters	Increase injection temperature and decrease flow rate
Injection pressure	Adjust pressure
Soluble strength	Dip fragile section in core print wax
Soluble degradation	Pattern wax is too hot and is melting the core Decrease temperature of pattern wax or change feed location
Sprue location	Check area of sprue-located near pressure sensitive area Change location to less sensitive area

6) AIR BUBBLES

CAUSE	CORRECTIVE ACTION
Wax too hot	Lower wax temperature - decrease turbulence.
Wax flow	Decrease wax flow
Sprue location	Check location of sprue for entry area where the least amount of turbulence will enter
Wax conditioning & Transfer	Check wax at nozzle for air and/or increase wax temperature in reservoirso air bubbles can raise to the top of the tank
Die Venting	Add or enlarge vents. Clean vents and core pins
Release spray	Check vents for blockage due to spray

PATTERN DEFECTS : CAUSE AND CORRECTIVE ACTION

7) WAX PATTERN CRACKS

CAUSE	CORRECTIVE ACTION
Excessive hold time	Decrease cycle time
High injection pressure	Decrease pressure
Location of knock out pins	Locate pin position - make additions if need be
Pressure in tool	Check if vacuum exists - check vents
Mold opening	Check opening of tool Check draw - deep draw short guide pins parting line should separate evenly
Platen temperature - too cold	Adjust platen temperature

8) CAVITATION, SHRINK SINK

CAUSE	CORRECTIVE ACTION
Wax temperature too high	Decrease wax temperature
Injection sprue	If wax freezes off before the pattern solidifies, the pattern cannot be fed. Insulate or enlarge sprue
Hold time too short	Increase hold time
Wax flow	Adjust wax flow - increase or decrease
Injection temperature	Increase Injection Temperature
Sprue location	Change sprue location