

# Paraffin Mottling in Candlemaking



**THE INTERNATIONAL GROUP, INC.**

September 1999

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**ABSTRACT:** *The mottling phenomenon in petroleum waxes has recently been exploited by many candlemakers to provide a range of different appearances and textures to their products. The formation and mechanism of mottling in wax is discussed in this paper, focusing on the crystal structure of the candle. Results of work are presented on how critical factors such as fragrance and dye levels, additives, and process factors act to promote or inhibit this phenomenon.*

The term *mottling* has been used in the agricultural, ink and photographic industries to describe a marbled, mosaic pattern. The term *mottling* has also been adopted by the candle industry to describe a white, snowflake-like formation in certain paraffin waxes (also described as snow spotting, starbursts and flowering). Because the exact description of mottling is a subjective one, this investigation defined paraffin mottling as the formation of small, white inclusions (usually less than 1mm) in paraffin wax that form a sharp contrast with a background color. By definition then, the appearance of fractures and cracks from quench cooling paraffin wax are not considered to be mottling. The title page photograph illustrates a series of commercial candles emphasizing the range of effects possible with varying degrees of mottling.

Paraffin mottling in candles is also subject to interpretation in terms of the severity or percent surface coverage occurring on the candle. This issue has been the focus of controversy in terms of what the wax supplier can provide

and what each individual customer desires. Whereas one candlemaker finds one hundred percent surface mottling acceptable, another may feel that only "a few snowflakes" are required to sell the final product. To help eliminate confusion, the degree of mottling observed was defined in terms of percent surface area coverage measured along the sides of a votive candle with a height and diameter of approximately 4.5 cm.

The goal of this research was to explore the mechanism of mottling and to understand how various additives, fragrance bases, cooling rates, fragrance and dye levels, and crystal morphology affect the degree to which paraffin wax mottles.

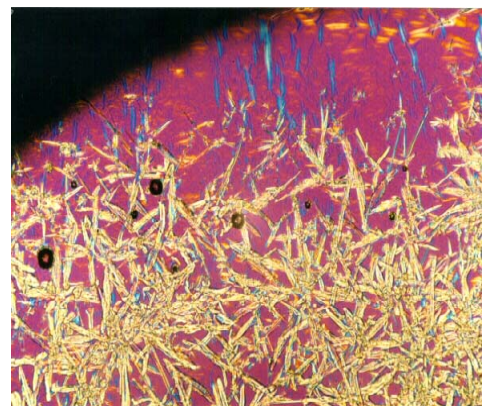
### The Mottling Phenomenon

Microscopic evaluations were performed on IGI 1274, a mottling paraffin wax produced by THE INTERNATIONAL GROUP, INC. (IGI), loaded with a commercially available fragrance and dye at a combined 5% concentration by weight. The paraffin wax was melted at 75°C (167°F) and slowly cooled to room temperature on a thermally-

controlled microscope stage. Nucleation of the wax crystals began at around 60°C (140°F) which led to the growth of large, needle-like crystals that increased in length and breadth as crystallization proceeded. This large, needle-like crystal growth common to mottling waxes is illustrated in figure 1. The developing crystals come in contact with one another as their growth progressed until a solid network of interlacing needles was formed.

Once initial crystallization was

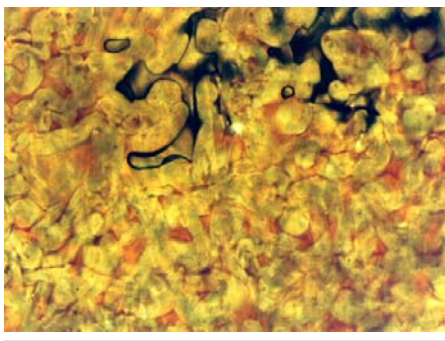
**Figure 1:** Needle crystal formation of a mottling wax at 55°C (131°F) and 32 X magnification.



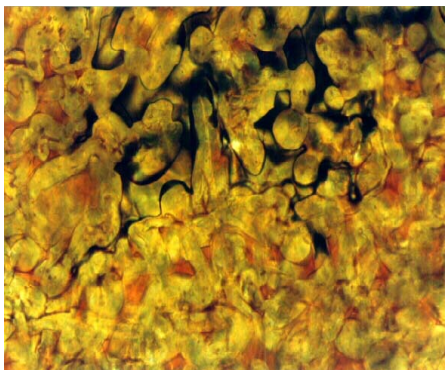
complete, there was a short time lag while the wax further cooled to a temperature of 40°C (104°F). At this point, a solid-solid transition point, defined as the temperature at which solid wax re-crystallizes, was reached. Mottling occurs following this phase transition temperature and is thought to be initiated by contractions in the crystalline boundaries leading to the formation of micro cracks and bubbles. A vapor phase (thought to be air) propagates through the wax as

## Mottling

**Figure 2a:** Propagation of vapor phase between crystallites in a mottling wax under magnification. The blackened areas are the result of vapor displacing the red liquid (dye) phase. Crystals



**Figure 2b:** Propagation of vapor/liquid phase between crystallites. Notice the movement of vapor phase between crystals from figure 2a to 2b.



the paraffin goes through a solid transition phase and displaces the liquid medium existing in the crystal interstices (see figure 2). The vapor phase migrates between the crystals to displace the liquid provided that sufficient liquid phase is present to reduce cohesive strength between the crystallites. This resultant mottling propagation then forms significantly larger gaps between crystals. The impetus for the liquid displacement is the contraction or shrinkage that occurs upon cooling during the solid transition phase. The larger gaps resulting from the propagation of vapor and liquid between crystals are seen macroscopically as visible voids better known as mottling. The white snowflake pattern observed in the paraffin is the result of light refraction at the crystal interfaces.

### Factors Affecting Mottling

#### Fragrance and Liquid Dye Levels

Using a statistically-based experimental model, the effect of liquid fragrance and dye levels were evaluated with respect to surface mottling. Votive test candles were prepared using IGI 1274 mottling wax blended with a commercially available cranberry fragrance and red liquid dye. All test candles were poured at 82°C (180°F) and cooled to ambient temperature. Percent surface mottling was recorded two hours following the pour time.

Fragrance oil and dye were added at the following levels:

**Fragrance oil:** 0.5%, 1.5%, 2.5%

**Red dye:** 0.025%, 0.100%, 0.175%

Statistical interpretation of the resulting data clearly showed a positive correlation between fragrance level and the percent surface coverage of the mottling. The analysis done on dye levels showed a weak correlation perhaps due to the liquid phase contribution of the dye itself. It was found however, that dye is important in providing the color contrast required in order to see mottling clearly.

#### Fragrance Bases

Five common fragrance bases were evaluated for any discernible contribution they may have on paraffin mottling in test votives. The bases listed below were combined with a known concentration of dye and added to the mottling wax at 1%, 2% and 3% levels.

- Benzyl benzoate
- Dioctyl phthalate
- Dioctyl adipate
- Hercolyn D
- White mineral oil

Results from this experiment showed that increasing levels of base has a positive correlation with percent surface mottling. There was little difference observed between the *type* of base used and the percent surface coverage recorded. From the data it was concluded that the concentration of liquid phase present in the wax is the critical factor with respect to percent mottling and not the individual chemistries of the bases.

While these conclusions regarding fragrance and dye levels apply only to the system investigated, the findings should still be considered of importance to the candle industry.

#### Cooling Rate

Studies on the effect of cooling rate and cooling medium on mottling were conducted using water baths at various temperatures and ambient air conditions. Since the exterior of a candle cools at a faster rate than the interior, the effects of accelerated cooling using a liquid medium at different temperatures were investigated.

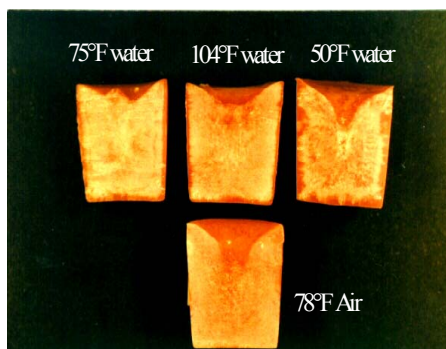
Water cooling at temperatures of 24°C (75°F) and 40°C (104°F) produced no *surface* mottling. However, cross sectional views of the test votives revealed that over 90% of the wax *interior* had mottled completely. A similar effect was observed with a votive quench cooled in ice water. Air cooled votives showed 100% surface and interior mottling demonstrating that the means in which the candle exterior is cooled determines the cooling rate of the candle and whether the surface will mottle or not (see figure 3). Tests showed that very rapid chilling of mottling paraffin produces smaller crystals



which yield a more uniform, tightly packed network which prevents the

**Figure 3:** The effect of cooling rate on mottling using water and air media

- a) water cooled @75°F      b) water cooled @ 104°F  
c) cooled in ice bath      d) air cooled @ 78°F



formation of mottling.

#### Pour Temperature

The impact of pour temperature on percent mottling was investigated at three different temperatures: 71°C (160°F), 77°C (170°F) and 82°C (180°F). Test votives with controlled fragrance oil and dye levels were cooled naturally to room temperature following the pour at a specified temperature. There was no correlation apparent between pour temperature and percent surface mottling. All test votives mottled in a similar manner.

#### Mottling and Fragrance Bleed

It was observed that test votives exhibiting a high percentage of surface mottling also demonstrated severe fragrance and dye bleed. Conversely, low percentage of surface mottling showed little bleeding of oil.

#### Mottling and Cavity Formation

Most candles tend to form a depression or cavity upon cooling due to the difference in cooling rates between the exterior and interior sections. The depth of the depression in the test votives showed a positive correlation with

the percent mottling. Test votives with a high percentage of surface mottling tended to have drastically reduced depressions, whereas votives with a low percentage of surface mottling tended to form much deeper cavities. This is presumably due to shrinkage in the mottle as opposed to the center of the candle.

#### Mottling and Candle Additives

The effects on mottling of the following common candle additives at a 0.25% addition rate were explored :

- Vybar<sup>®</sup> 103 poly (alpha olefin)
- Ethylene vinyl acetate (EVA)
- AC-6 polyethylene
- Microcrystalline wax
- Stearic acid

Experiments were carried out using IGI 1274 mottling wax formulated with 3% fragrance and dye, and an additive from the above list. The mottling wax was found to be sensitive to the addition of these additives. The blends containing EVA, Vybar<sup>®</sup> or polyethylene exhibited no mottling (see figure 4). The blend containing microcrystalline wax additive exhibited 5% surface mottling and the stearic acid containing blend appeared similar to the control (90-100% mottling).

**Figure 4:** The effect of various chemical additives at 0.25% (w/w) on mottling: a) Vybar<sup>®</sup> b) EVA c) Polyethylene d) Control e) Microcrystalline wax f) Stearic acid



The experiment was repeated using 1% levels of microcrystalline wax and stearic acid. Microcrystalline wax at a 1% concentration completely eliminated mottling and the blend containing stearic acid produced 50% surface mottling. Progressive elimination of surface mottling using stearic acid at 3%, 5% and 10% was observed. Mottling was completely eliminated at a 10% level.

#### Summary of Findings

Mottling waxes are comprised of large crystals that form an open or "loose" network when viewed microscopically. The following factors were observed and conclusions drawn in relation to mottling:

- A liquid phase must be present, existing in the form of fragrance oil, liquid dye, soft wax components, or mineral oil. Increasing the liquid phase helps to reduce the cohesive forces between crystals thus allowing for the formation of void spaces.
- Slow air cooling of the candle is required for mottling to occur especially in terms of surface mottling.
- There is a positive correlation between the amount of fragrance oil and the degree in which a candle will mottle. The main role of the dye is to provide background contrast to the mottling.
- Different fragrance bases (liquid phases) did not seem to have an effect on the degree of mottling observed.
- EVA, polyethylene, Vybar<sup>®</sup> and microcrystalline additives tended to inhibit mottling.



# THE INTERNATIONAL GROUP, INC.

## About IGI

THE INTERNATIONAL GROUP, INC. (IGI) is a customer driven corporation committed to understanding and satisfying customer's needs.

Founded in 1945, IGI has grown from a small independent Canadian refinery to a global leader in the refining and compounding of petroleum waxes, amorphous (atactic) polypropylene (APP) products and specialty ployolefin compounds.

Today, IGI owns and operates the largest independent, ISO 9001 registered, petroleum wax refinery/blending plant in North America. This is in addition to terminal and blending facilities, warehouses and sales offices located throughout North America.

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