“Stainless” BMC – A Polymer Alternative to Stainless Steel

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Introduction

Stainless steel appliances have long been synonymous with quality, durability and price reserved primarily for the restaurant industry. Meanwhile, for numerous years, in order to be cost competitive in mainstream America, high volume brand name manufacturers have avoided the stainless steel appearances and focused more on products comprised of pre-painted steel and color matched plastic components. Recently, however, stainless steel has successfully crept into the mainstream, finding a niche with some large brand name manufacturers. With a growing desire for this appearance, it will be difficult to combine high volume production, design flexibility and affordability using traditional methods. Thus, manufacturers have set out to determine a way to produce stainless steel appliances that fall within what consumers consider the acceptable selling price range. One avenue that has been pursued with minimal success is importation of steel either in its raw form or already prefabricated. U.S. tariffs make importation of raw steel impossible without hefty penalties, and prefabricated parts demand long lead times and large inventories, which adds cost. Currently, a new avenue is being pursued that to date offers the most cost effective method of achieving stainless steel. It has been found that by combining knowledge of BMC molding, vacuum deposition techniques and UV-curable technology, which has already been proven successful in a stringent automotive forward lighting market, there is now an affordable alternative to stainless steel.

Project Overview

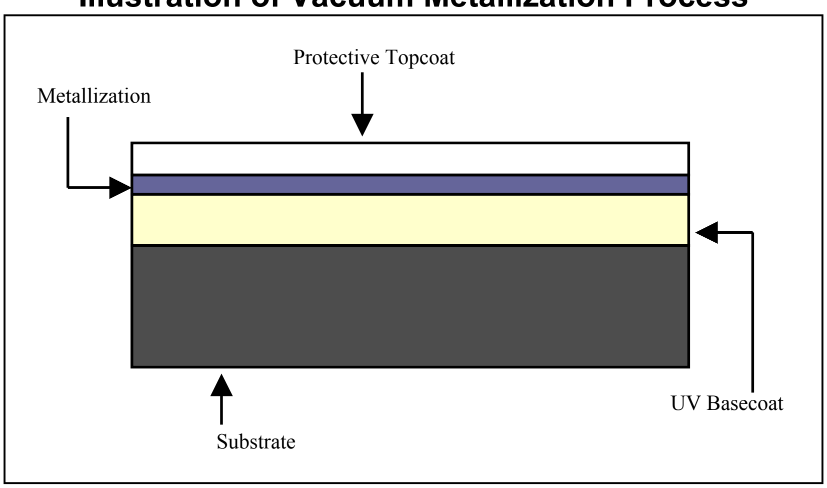
Bulk molded compound (BMC) is a thermoset agglomeration of glass reinforced polyester, inorganic mineral fillers and specialty additives. When BMC is molded, typically by an injection process, it undergoes an irreversible cross-linking which provides substance and stability especially in harsh high heat environments. With a flex modulus in excess of 1.9 MPSI and a specific gravity of 1.8-2.0, BMC is a solid and sturdy yet light weight material that is an excellent choice over thermoplastics for applications requiring stringent high heat resistance and electrical or structural integrity. However, because formulation and molding/processing techniques have been rather crude, BMC applications have been limited primarily to non-visual areas of small and large appliances, as well as under the hood automotive applications. Additionally, and probably familiar for many UV coatings formulators, BMC has been a mainstay in automotive forward lighting as a replacement for thermoplastic materials in reflector applications. BMC was first introduced into the automotive forward lighting market in the mid 1980’s and continues to be a popular material because it is economical at less than \$1.00/lb (\$0.05-\$0.08/in^3), it is highly compatibility with coatings and adhesives, and it offers the flexibility in molding needed to produce complex 3-D parabolas.

In these automotive applications where a lustrous appearance is a necessity, basecoats have long been required to provide a high gloss surface that accepts metallization. Further with the evolution of lighting design, many fluted headlamp lenses have been replaced by optically clear lenses that expose the appearance of the underneath reflector. Because of this design, these basecoats must also provide a near perfect appearance with exceptional smoothness and defect free surface. With these rigorous demands, UV coatings have found a home in this arena not only because of their ability to flow and level, but also because of their rapid cure time, low scrap rates and recycle-ability. Further, because designs have become increasingly more complex with hot pockets and high stress areas, UV coating technology has had to evolve to withstand heat stability in excess of 400°F and rigorous hot to humidity to cold cycle tests with temperatures ranging from -40°F to 400°F.

Headlamp Assembly with BMC Reflector and Optically Clear Lens

On top of the organic basecoat surface, a thin layer of metal commonly aluminum or a chrome alloy is deposited via a vacuum process resulting in a highly reflective surface. The addition of this metal layer magnifies processing or environmental defects reinforcing the need of near perfect appearance. On top of the metal layer, a second coating is applied to protect the metal from oxidation and to provide necessary performance properties. This top coat layer can be UV curable, but because minimal performance properties are necessary, it is more commonly a siloxane based coating applied in-chamber after metallization.

Illustration of Vacuum Metallization Process



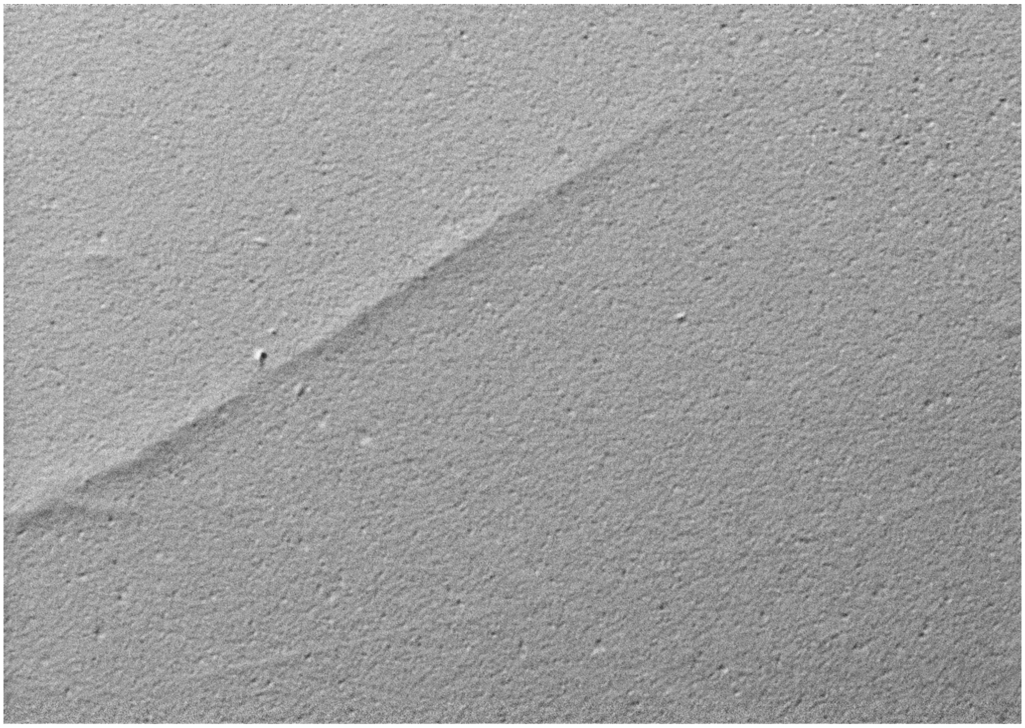
In today's world where the emphasis is on leaner manufacturing and elimination of processing steps, many plastics manufacturers including BMC suppliers have focused much time and effort in developing substrates that do not require a basecoat application. This process has yet to be mastered for high profile automotive applications, but during the development process the concept of sputtered stainless was born. As mentioned previously, BMC molding and processing techniques to date have been rather crude, so it is no surprise that some of the first attempts at no basecoat BMC resulted in parts that did not hide defects or scratches of the mold. Further, in these trials, just as with coated BMC, it was obvious that the metallization step will not mask, but instead intensifies surface defects. However, it was noted that many of these first attempts at a no basecoat BMC resulted in a brushed look that resembles 304-type stainless steel. In order to perfect the stainless appearance on BMC, much effort went into substrate formulation such that the correct look and brilliance are achieved after metallization. Further, molding issues such as gate blush, heat smear, knit lines and ripple had to be addressed such that a convincing stainless appearance is achieved.

Finally, just as the metallization layer of an automotive reflector must be protected from oxidation so too must the metallized stainless metal layer. However because the life expectancy of most appliances is in excess of 10 years, and because they are more exposed to environmental conditions versus an enclosed reflector, the targeted applications require a much more durable and robust topcoat rather than popular in-chamber hexamethyldisiloxane (HMDSO) topcoats used in automotive. Another option for this protective topcoat is fluoro-polymer technology, which is currently used as a surface enhancement for other BMC appliance applications, but it requires cure cycles with temperatures in excess of 400°F making it not so attractive. Thus, much effort has been devoted to developing a UV-curable topcoat because of the normal advantages associated with UV: low energy consumption, quick cure cycle, reduced work in process, reduced scrap, and most importantly superior properties.

Experimental Discussion and Results

In order to achieve the durability and abrasion and chemical resistance necessary for appliance applications, much information was drawn from already established knowledge in the automotive forward lighting market where UV coatings have been successful as basecoats for BMC, as topcoats over vacuum deposited metal, and as hard coats over polycarbonate lenses.

Focusing first on adhesion of this UV top coat to the stainless layer, in the metallization step, a very thin layer (~500-800 angstroms) of stainless steel is deposited on the substrate. This film is not continuous, so to achieve adhesion with the UV top coat, means of gaining adhesion both to metal and BMC were considered. Various resin types and functionalities as well of specialty additives were evaluated and a blend of lower functionality resins and adhesion promoting additives were identified to provide optimum adhesion. Further, as seen in many reflector applications, adhesion to BMC can be enhanced mechanically due to the porosity of the substrate. Especially because there is a need to mold brush marks into the substrate to mimic a stainless look, enhancement of adhesion by mechanical means greatly applies.



(400x) SEM Topographic Mode Depiction of BMC Porosity

Next, in order to achieve the durability as well as abrasion and chemical resistance, required for appliance applications, hard, highly functional urethane acrylate oligomers were blended with the lower functional oligomers and monomers similar to what has been done for protective clear coats used on automotive headlamp lenses. This provides a final film that is much superior to competing 2-component thermal cure coating in regards to both chemical and abrasion resistance.

Table 1: Comparison of UV Curable Topcoat and 2K Thermal Cure Topcoat

	UV	Thermal
Cross-hatch Adhesion	O	O
Water Soak x 24 hr. at 38°C	O	O
HCl Acid Resistance	O	X
Salt Spray x 240 hr	O	X
Falling Sand Abrasion (30L)	O	X

Note: O = acceptable, Δ = marginal, X = failure

Finally, the gloss of the UV coating had to be altered slightly to provide a convincing stainless appearance rather than a cheap plastic look. This simply was achieved with the addition of wax treated silica flatting agents. Additional matting agents and flow additives can be used in conjunction with the silica to enhance appearance and feel.

The current formulation has been exposed to a variety of performance specifications to ensure that its performance resembles 304-type stainless steel. Among the more critical factors for appliance applications are the plethora of chemical resistance requirements.

Table 2: Chemical Resistance Testing Performed at Room Temperature x 24 hrs.

Reagents	UV Curable Top Coat	304 Stainless Steel
Liquid All Laundry Detergent	O	O
Soft Scrub Abrasive Cleaner	O	O
Windex Glass Cleaner	O	O
Fantastik All-Purpose Cleaner	O	O
Barkeeper's Friend Stainless Cleaner	O	O
Joy Dishwashing Detergent	O	O
Easy Off Oven Cleaner	O	O
Ammonia	O	O
Ragu Spaghetti Sauce with Meat	O	O
Vinegar	O	O
French Dressing	O	O
Concentrated Orange Juice	O	O
Cranberries	O	O
Chocolate Syrup	O	O
Instant Coffee	O	O
50% Bacon Grease/50% Oleic Acid	O	O
Crisco/Beef Tallow	O	O
Mustard	O	O
Catsup	O	O
Lemon Juice	O	O

Note: O = acceptable, Δ = marginal, X = failure

Table 3: Chemical Resistance Testing Performed at 120°F x 24 hrs

Reagents	UV Curable Topcoat	304 Stainless Steel
Plochman's Mustard	Δ	Δ
Red Gold 100% Tomato Juice	O	O
Real Lemon Juice	O	O
Lipton Tea	O	O
Coffee	O	O
Salt Water (10% by weight)	O	O
Mr. Clean (50% in water)	O	O
Dean's Vitamin D Whole Milk	O	O
Crisco Vegetable Shortening	O	O
Lard	O	O

Note: O = acceptable, Δ = marginal, X = failure

Conclusion

Despite the cost typically associated with stainless steel, the desire for such products continues to grow in mainstream America. In an effort to find an affordable offset to stainless steel, various industry suppliers have teamed up and combined knowledge of BMC molding, vacuum deposition techniques and UV-curable technology to hit this target, and actually this can be achieved with cost savings upwards of 30%. Large parts with little detail such as refrigerator door panels and oven side walls can still be mass produced most efficiently by traditional rolled metal techniques. However, "stainless" BMC is well suited for more detailed trim designs such as handles, knobs, control panels, shelving and vent trim. Further, as shown in results above, this brushed stainless steel look can be achieved without sacrificing any of the exceptional durability or quality typically linked with stainless steel.

References

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