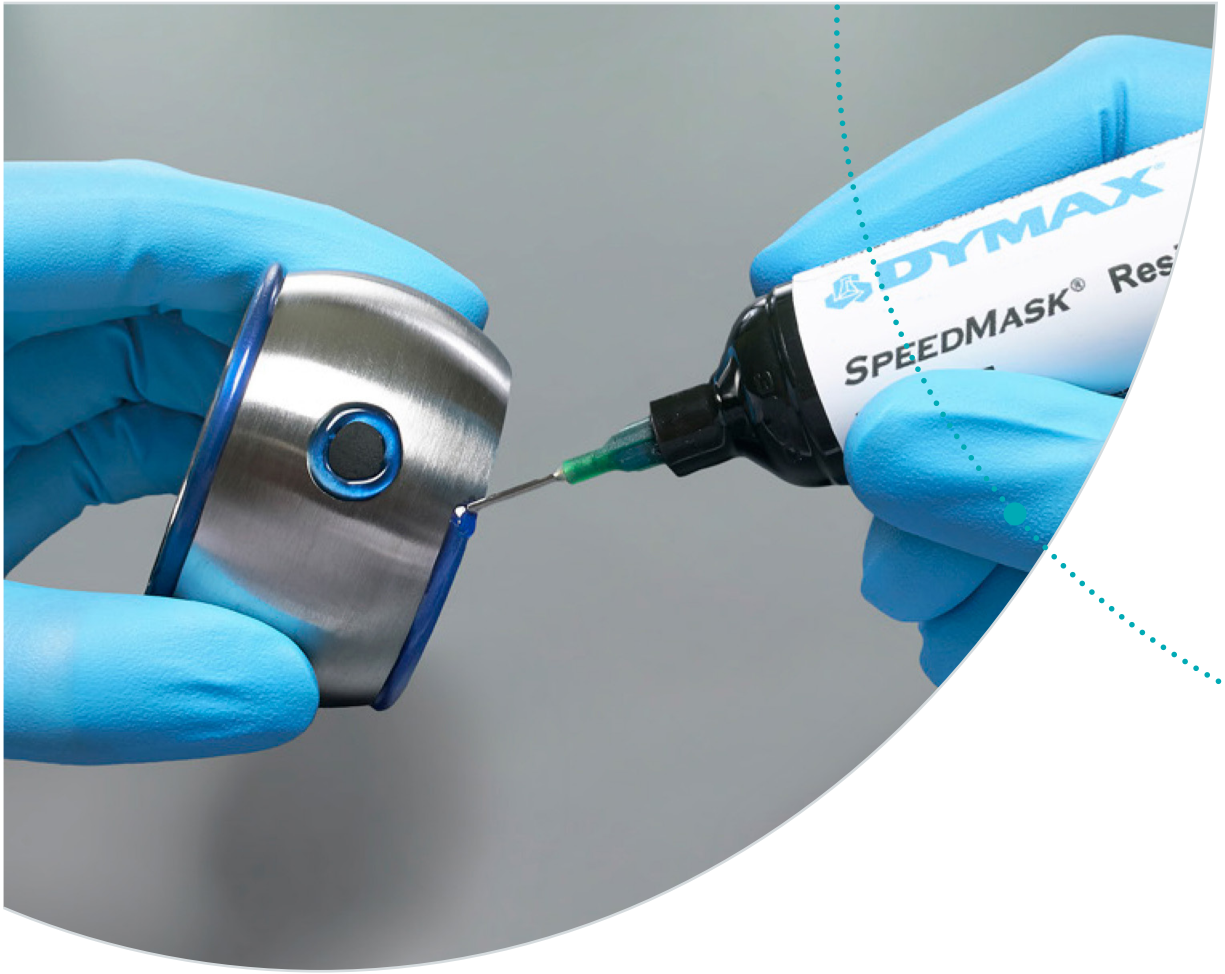

Light-Curable Maskants:
An Alternative to Traditional Masking Methods

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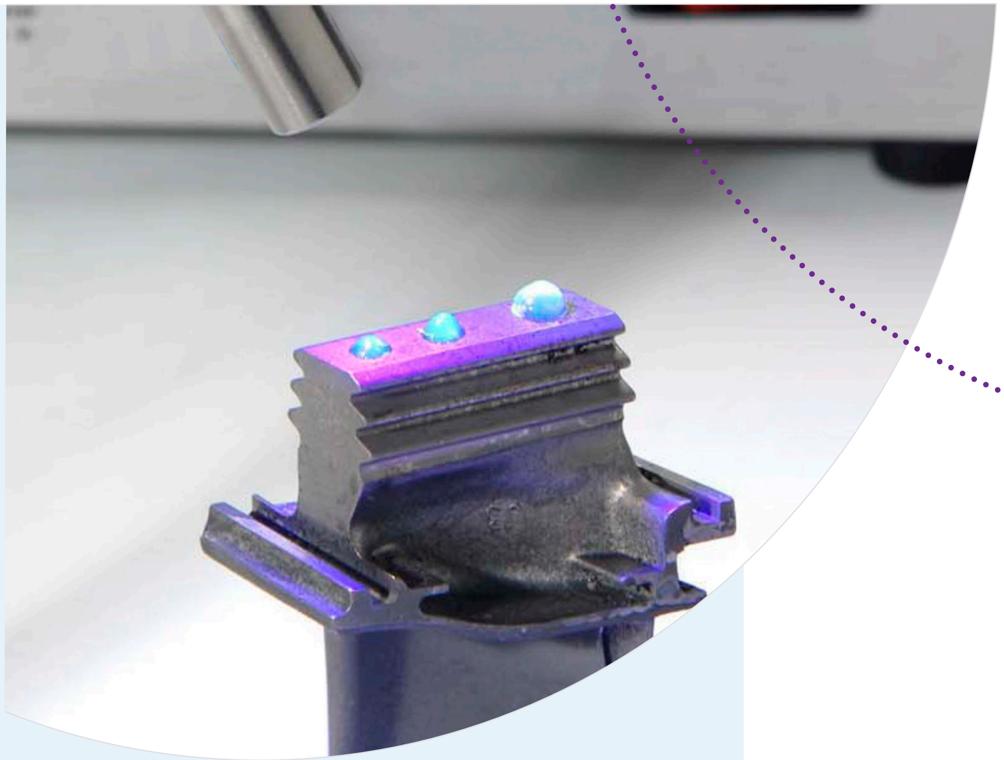
DYMAX®



Abstract

A line of solvent-free, light-curable temporary masking resins has been developed to simplify component masking processes prior to surface preparation and finishing operations. These maskants cure in seconds under UV light and provide superior protection during surface finishing processes such as machining, laser drilling, grit blasting, shot peening, acid stripping, plating, and thermal spray coating.

Their ease of application, speed of cure, and consistent reliability surpasses that of waxes, tapes, lacquers, and other slow curing, solvent-based maskants. This improved technology offers substantial cost savings through reductions in labor, rework, and scrap.

Introduction

Masking of components and surfaces is a necessary part of every surface finishing process. Whether for abrasive cleaning, acid stripping, shot peening, plasma spray, or plating, masks act as a self-sacrificing barrier for surface protection. The process of masking may seem simple enough, but a thorough analysis reveals that it can add significant costs to any operation. These costs may not be readily visible, as the masking material is typically not the major contributing element to cost. Rather, it is the masking process itself (specifically the labor) that can be the major cost factor. The more intricate a component, the longer it takes to apply and remove traditional masks, such as tapes, waxes, and solvent-based lacquers. In addition, there are other hidden costs associated with using these masks. They can include scrap, component rework, production bottlenecks, workman's compensation claims, and higher insurance premiums. When the cost of labor is factored in with the other hidden costs, it becomes apparent that simply using a lower priced masking material will not provide the desired cost savings that are required for greater competitiveness in the market.

When traditional paths cannot offer tangible savings opportunities, the door must be opened to alternative technologies, like light-curable maskants.

Traditional Masking Methods

The most popular products in today's masking applications include tapes, waxes, lacquers, and reusable boots and plugs. These products have been used for years, sometimes interchangeably within the same process. Until recently, very few new alternative products have been made available for temporary protective masking.

Tapes

Masking tapes range in composition from simple, low-cost paper tapes typically associated with painting, to expensive, heat-resistant polyester, polyimide and silicone used in high-temperature surface finishing. Tapes are dispensed from a roll and are cut to fit the area to be masked. Some can be purchased in die-cut shapes, but this can be costly and is usually limited to high volume production of a single component configuration.

Pressure sensitive adhesive backing allows the tape to adhere to surfaces. Unfortunately, residue from the tape's adhesive can remain on the surface after the tape is removed. A subsequent cleaning operation is often required to remove the residue.

Tapes are durable enough for most masking applications involving one cycle of a dry process, such as shot peening or grit blasting. However, particulate often finds its way under the tape into inner core cavities, necessitating secondary removal and cleaning operations. Cleaning and plating baths also expose inadequacies in the manual tape application process. The liquid baths creep under the edge of the tape and flow quickly through creases and areas of low adhesion between the tape and component surface.

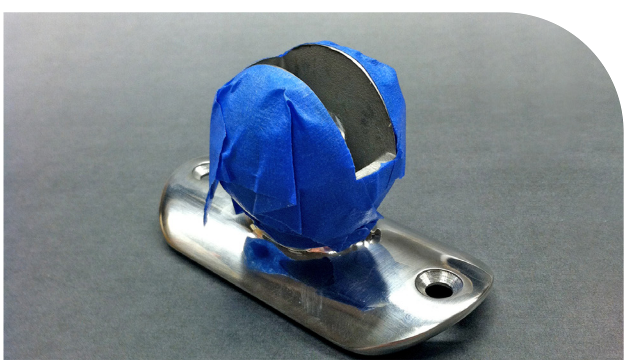


Figure 1. Part Masked with Tape

Masking with tape is perhaps the most labor-intensive masking process. Tapes are applied by hand, and in most cases of multiple surface processing operations, reapplied in the same areas due to abrasion and wear. It is not uncommon for an operator to spend 2 to 4 hours masking a single intricate component.

The taping process itself, in addition to being time consuming, can also create a hazardous work environment for employees. Despite the best protection, employees can sustain finger cuts from razor blades and from the tape itself. These injuries can result in lost time, workman's compensation claims and higher insurance premiums.

Boots and Caps

Boots and molded caps, typically made of rubber or vinyl, are used in high-volume processing of components with no dimensional variations. Because the cost of molds can be quite high, it is cost prohibitive to have boots and caps molded for small volumes or components with varying configurations or dimensions. Thus, molded boots and caps are not universal masking media. Rather, they are very product specific.

Boots and caps rely on press fit tolerances and their elasticity to affix themselves to the components. However, this is not adequate protection for liquid processes like acid cleaning and plating. Boots and caps will eventually wear out after repeated use. They can also loosen and fall off during the process creating costly rework or scrap.

Waxes

Wax is perhaps the least expensive material that can be used for masking. However, it is difficult to work with, as it must be heated above its melting point to apply (150ºF or higher). Heating requires special handling equipment and thermal energy which can generate a surprisingly high utility cost. Operators also face the possibility of burns when repeatedly handling the hot wax. Typically, wax is poured into components to protect internal cavities. Parts with tight dimensions and serpentine pattern cavities must be pre-heated to allow proper flow of wax. Dipping is the only practical method of coating external surfaces, because hot wax cannot be applied in a controlled fashion.

Removal of wax requires the same melting process as application of wax, with the exception that the component must now be heated with the wax. Again, operators must take precautions to avoid being burned by the wax and the components. Wax removal is usually conducted in a hot water bath. Care must be taken to ensure all wax is removed from the components, and the water bath must be well filtered or replaced frequently to keep the water clean. Melted wax creates a film in the water which can be redeposited on the components as they are removed from the tank. An additional cleaning operation is often required after wax removal. If any residual wax remains in core cavities, it may be necessary to burn it off in a furnace.

The low melting point of wax limits or prevents its usage in high-temperature surface treatment processes such as acid cleaning, plating, and deposition coating. In addition, wax is soft. Precautions must be taken during handling to prevent accidental damage to the coating which could result in rework and possible scrap.

Lacquers

Typical masking lacquers are solvent-based and require a prescribed curing time to allow the solvent to evaporate and the remaining resin to cure, or harden, on the components. This type of curing process requires the masked components to be stacked or racked and left undisturbed for several minutes to several hours. Not only is the process bottle-necked, but valuable production space is consumed with curing parts.

The solvents contained in many lacquers are the same solvents that are being restricted or banned in the workplace by governmental agencies for health and safety concerns. Evaporating solvents such as xylene, toluene, and other acetates have been linked to respiratory problems and other long-term ailments. Elaborate exhaust and air handling systems are mandatory when using solvents and solvent based products in the workplace. In addition, solvents can be extremely flammable, posing another health and safety risk.

Solvents, and products containing solvents, must be carefully monitored in the work environment. The U.S. Environmental Protection Agency mandates that consumption reports be filed for all solvent-based products. Solvent-based waste must be recognized as hazardous material and disposed in accordance with strict guidelines. In addition to higher waste disposal costs, insurance premiums can be considerably higher for manufacturers using solvents and solvent-based products. For these reasons, many corporations have mandated that solvents be phased out of their facilities as soon as possible. Some water-based lacquers have been introduced to overcome the solvent issues. However, they do not possess the same strength as solvent-based lacquers, and they require the same prolonged curing time, which can vary based on air temperature and humidity.

Lacquers are predominantly watery, low-viscosity products. In order to provide adequate protection as a mask, it may be necessary to repeat dispense and cure cycles several times to build the proper mask thickness. Multiple masking cycles create delay and add cost.

Finally, lacquer removal can be a difficult process. Typically, lacquer-masked components are first warmed, then soaked in a solvent such as acetone. The majority of the lacquer slumps off the components, but some patches remain on surfaces and in cavities. Additional labor may be necessary to remove the lacquer remnants through subsequent processes involving grinding and burning.

An Alternative Solution - Light-Curable Masking Technology

The History of Light-Curable Maskants

The technology for light-curable maskants originated from UV-curable aerobic acrylic adhesives and coatings. Commercialized in the early 1980s, aerobic acrylic adhesives and coatings have provided new efficiencies to manufacturers, resulting in millions of dollars in cost savings.

Significant contributions include:

- **Increased thru-put.** UV-curable aerobic acrylics take seconds to cure instead of hours. Curing bottlenecks are eliminated, resulting in significant productivity gains.
- **Worker and Environmentally Friendly.** UV-curable aerobic acrylics do not contain solvents, eliminating special handling requirements and costly ventilation systems.
- **Minimal Capital Investment.** UV-curable aerobic acrylic adhesives and coatings are cured with lamps that produce ultraviolet energy. Lamps of many styles are available at moderate cost. Investment in an average light-curing system is typically recovered in the first year of operation, or sooner.
- **Easily Integrated into Automated Production.** UV-curable aerobic acrylics can be dispensed in a variety of ways including bead placement, dip, spray, pad print or screen print. Light-curing lamps are easily placed into existing production lines, utilizing minimal space for curing.

First introduced in the mid 1990s, light-curable maskants have the potential to provide similar, if not greater, cost reductions in the current plating and surface finishing industry. The ability to apply a light-curable maskant and cure it instantly facilitates uninterrupted component processing. For ease of use, these maskants offer many viscosity variations, from the consistency of water to non-flowing gels. This permits controlled coverage, including coating depth, in a single application. They are easily dispensed, both in manual and fully automated processing lines. Conventional, labor-intensive masking can be replaced with semi-automated or automated systems that provide controlled spraying, dipping, or precision placement of the light-curable, liquid maskant. The superior adhesion and exceptional resiliency of the maskant can also improve component quality by reducing post-processing rework and scrap, arising from deficiencies in traditional masking methods and products. The durability of light-curable masks makes it possible to mask only once for multiple surface processing operations, eliminating stripping and remasking between processes. Simply stated, this increased efficiency leads to lower cost.

Light-Curable Masking Technology

Worker friendly and OSHA compliant, light-curable masks are solvent-free, low odor, non-flammable, liquid resins that cure in seconds upon exposure to ultraviolet light energy. They are specifically formulated to have no effect on the metallurgy of the surface being masked. These resins are urethane based, and contain no heavy metals, silica, or other compounds which can alter properties of the component surface or the finish being applied. Once cured, these resins can be handled like any industrial plastic. When removed by recommended methods, light-curable maskants leave no residue behind.

Uncured maskants possess a high degree of stability which permits long shelf life (up to a year) when stored under ambient conditions (50-90°F). Refrigerated storage is not required. These resins are single component formulations, eliminating the need to measure and mix prior to using. Light-curable maskants are available in a variety of containers to accommodate any dispensing system, ranging from small syringes to bulk packaging measured by volume or weight.

While some may be simple formulations and others more complex, light-curable maskants are typically comprised of five basic elements: Photoinitiators, additives, monomers, modifiers, and oligomers. (Figure 2).

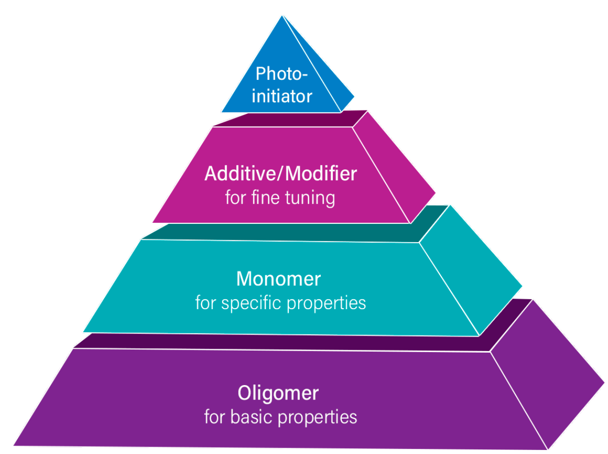


Figure 2. Typical Light-Curable Urethane Acrylate Maskant

- **Photoinitiator (P.I.) –** Component of the light-curable maskant that begins the polymerization (curing) process when exposed to UV light energy of a compatible wavelength. In dual curing resins, a secondary initiator may also be included which utilizes heat to begin polymerization. Dual cure resins are used in areas where UV light cannot reach and fully cure the masking resin, such as core cavities.

- **Additives –** Filler chemicals that are used to add or enhance specific resin properties such as flow rate, wetting, tack-free surfaces, color or fluorescence.

- **Modifiers –** Component of the light-curable maskant that can increase durability by improving impact and crack resistance of the resin.

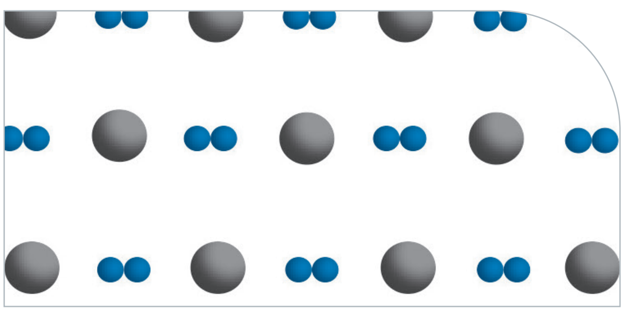
- **Monomers –** Single units of polymers which provide adhesion to surface materials such as titanium, aluminum, iron, and nickel or cobalt based super alloys.

- **Oligomers –** Oligomers are the backbone of the resin and are comprised of medium length polymer units which provide the basic properties of the light-curable maskant such as hardness, elongation, and chemical resistance.

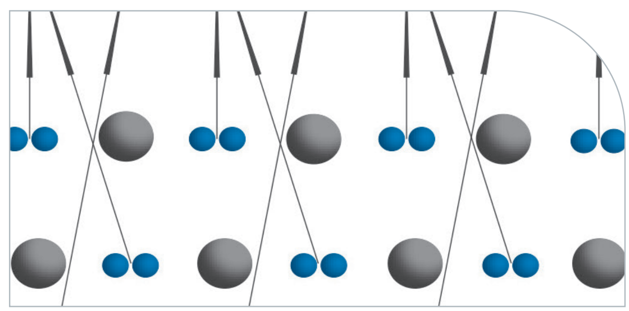
How Do Light-Curable Masks Work?

The light curing process begins when the photoinitiator in the mask is exposed to a light energy source of the proper spectral output. Its molecules split into free radicals (initiation), which then begin to form polymer chains with the monomers, oligomers, and other ingredients (propagation), until all of the ingredients have formed a solid polymer (termination) (Figure 3). What was once a liquid, is now a solid resin.

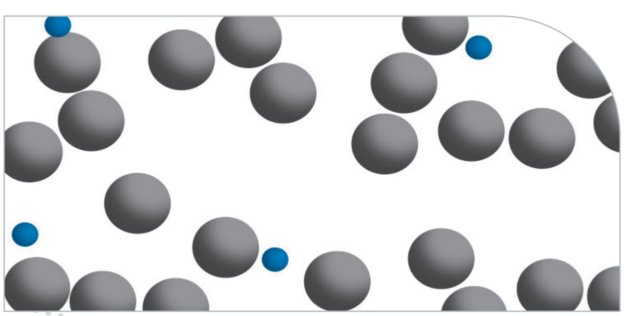
Figure 3. Light Cure Process



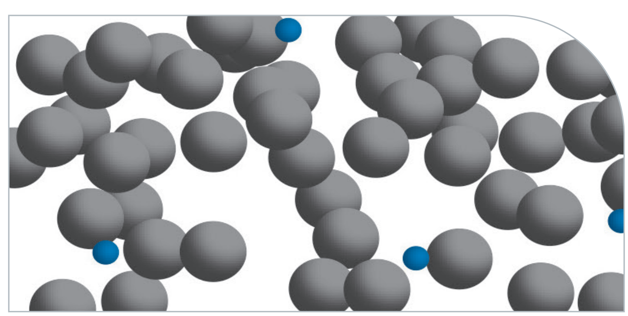
1. Liquid "unreacted" state



2. Photoinitiators generate free radicals



3. Polymer propagation



4. Polymer termination

Light-Curing Systems

Critical to the mask curing process is an ultraviolet light energy source. Several types of light-curing lamps and systems are commercially available. Spectral output of the lamp, intensity, component configuration, desired production throughput, and budget are all factors that help determine which type of light-curing system is appropriate.

Light-curing systems may be grouped into two very broad categories, spot lamps and flood lamps. Spot lamps generate high-intensity UV energy that is directed through a fiber or liquid-filled lightguide, typically 5-8 mm in diameter. These units are ideal for curing light-curable maskants in cooling holes or sealing off core cavities. For larger surfaces like airfoils and housings, flood lamps can be used which create light footprints up to 8" square. Systems are also available that combine curing lamps with conveyors for semi-automated production. This permits continuous in-line processing of components with no delays.

Once the appropriate curing process is established for a masked component, it cannot be varied without re-qualifying the process. This ensures complete cure of the maskant each and every time, which is essential for optimal adhesion and protection. The best source for assistance in selecting a curing system and qualifying a curing process is the manufacturer of the maskant. Their expertise with maskants and light-curing systems can help to implement a masking process with minimal time and expense.

Types of Light-Curable Maskants

There are three basic grades of light-curable maskants. They can be grouped by their removal mechanism: burn-off, peelable, or water soluble.

Burn-Off Masking Resins

These grades typically offer the best surface adhesion and provide the greatest resistance to heat and aggressive chemical solutions such as acid/alkali baths. Some burn-off grades also offer a secondary heat-curing capability for masking areas where light cannot penetrate. The heat-curable grades can be used for core cavity sealing to protect from debris, plating baths, and laser burn-through during drilling operations. Surface curing with light may take 20-30 seconds under a flood lamp, while heat curing may require 30-45 minutes in a 300°F oven.

Cure times can be slightly higher or lower based on the volume of maskant applied and size and configuration of the component.

The removal process for a burn-off grade mask requires the components to be baked in an air-enriched furnace between 900°F and 1,400°F. Typically, the higher the temperature, the shorter the bake cycle. However, duration of the bake cycle must be qualified for each specific series of masked components. Variables such as volume of mask applied, location of the mask (surface or core cavity), and thermal conductivity of the component will factor into determining the appropriate cycle time. Complete burn-off can be achieved in as little as 15 minutes for thinly coated surfaces. For core cavities, cooling holes, or thick mask coatings, a bake cycle of one hour or slightly longer may be required.

Obviously, burn-off masks are limited to parts that can tolerate high heat, such as the "hot" components of a turbine engine. In many cases, an existing heat treating operation may also be used to burn-off the mask. The burn-off process effectively incinerates the mask leaving no residue on the component surface. The composition of the maskant allows it to completely combust and be exhausted from the furnace. And, the metallurgy of the heat-treated component remains unaffected by the maskant.

A combustion study was conducted on a family of burn-off grade light-curable maskants by Oekometric GmbH – The Bayreuth Institute of Environmental Research in Bayreuth, Germany (Report No, 121/01 May 2001). The objective of the study was to evaluate potentially hazardous decomposition products that may be formed during the combustion of products based on polyurethane oligomers (light-curable maskants). The study and subsequent report concluded that combustion of these light-curable maskants creates fume gases which do not pose a risk in the workplace. In fact, combustion fume gases from this family of light-curable maskants were likened to those fume gases generated through combustion of other organic materials, including natural polymers such as beechwood.

Peelable Masking Resins

Perhaps the most versatile of light-curable maskants, the peelable grades, provide good adhesion to most clean, metal surfaces, are resilient enough to withstand a variety of surface treatment processes, and can be removed through a simple peeling process (Figure 4). Cured in a few seconds with UV light, peelable masks have been successfully qualified for surface protection in processes such as grit blasting, shot peening, acid cleaning, plating and anodized coatings. The surface bond is very strong and durable, possessing sufficient adhesion to survive through multiple surface cleaning and processing operations, eliminating the need to strip and remask between processes. Peelable light-curable maskants offer uniform adhesion from edge to edge, preventing processing media from creeping underneath.

Figure 4. Peelable Light-Curable Maskants

Peelable light-curable masks are removed by prying up an edge manually or with the help of a non-abrasive tool, then pulling. The elasticity of the material typically permits fast removal of the mask in one piece rather than in fractured segments. No residues remain on the surface after the mask is removed. The peeling process is made even easier by warming the cured masking resin to 120-150°F in a warm water bath or oven, or using a localized heating element.

The peeled material, essentially a plastic resin, is non-hazardous and may be disposed of in accordance with local regulations for industrial scrap plastic.

Water-Soluble Masking Resins

Water-soluble light-curable masks provide excellent protection for "dry" finishing processes such as grit blasting, grinding, shot peening, and plasma spraying. They can be applied using the same methods as the peelable grades. But the truly significant feature of the water-soluble grades is their removal mechanism. Unlike the burn-off and peelable grades, which are urethane-based, the water-soluble masks are formulated with water-soluble polymers. As their name suggests, the water-soluble grades dissolve in liquid. The ideal removal method utilizes heated water (140 - 180°F) and a spray wash or agitated/ultrasonic bath. The mask completely dissolves in the water leaving no residue on the component surface.

A closed-loop aqueous cleaning system is recommended for water-soluble mask removal. These systems are commonly found in existing surface finishing operations. It is thus possible to remove the mask and clean the components in the same operation, presenting another cost saving opportunity. The cured maskant does not contain any organic or inorganic toxic substances according to EPA, Connecticut, California, and Michigan Waste Discharge Listings. Light-curable water soluble maskants dissolved in water exhibit a neutral pH of 7 in up to 20% concentration and do not create a handling hazard to operators.

Process Saving Opportunities

Much emphasis has been placed on the cost savings that result from the use of light-curable maskants. Some savings are direct and easily calculable. Others, just as significant, are hidden in the indirect costs associated with traditional masking processes.

A detailed cost analysis comparing an existing masking process with a proposed light-curable masking process can bring actual cost savings into clear focus. In Table 1 below, a comparison is made between a low cost wax maskant and a burn-off grade light-curable maskant. The process involves an acid bath cleaning and subsequent grinding of a turbine component. Critical surface dimensions and the inner core of the component must be protected from the acid bath and debris. The wax process requires filling the core through a series of cooling holes and dipping a portion of the component for surface protection.

The light-cure method utilizes a high-viscosity light-curable maskant, permitting the operator to seal all the holes with a syringe type dispenser without filling the core. External surfaces are dipped in a lower viscosity version of the same maskant. After dispensing, the components are placed under a light-curing flood lamp for 45 seconds to cure. Through-put for the cleaning and grinding process averages 2,000 units per month. Processed components are valued at $2,500.00 each.

In the example in Table 1, several cost factors are reduced or eliminated by switching to a light-curable maskant. Less material is used due to the controlled viscosity of the resin. The resiliency and tenacious adhesion of the light-curable maskant eliminates stripping and remasking of the components between the cleaning and grinding processes. Scrap is reduced from 0.5% to zero. As components can range from several hundred to many thousands of dollars in value, the reduction in scrap alone is a significant factor.

Table 1. Cost Comparison - Low Cost Wax Maskant Versus a Burn-Off Grade Light-Curable Maskant

WAX			LIGHT-CURABLE MASKANT		
	Cost Per Unit	Total Time Per 20 Pc.		Cost Per Unit	Total Time Per 20 pc.
Wax (0.75 lb. at $3.40/lb.)	$2.50	---	Light-curable mask (0.33 lb. at $75/lb.)	$24.50	---
Warm parts in oven Labor*: 1 minute each Cycle: 20 minutes per batch	$1.00 ---	20 min 20 min	---	---	---
Apply wax for acid cleaning Labor: 30 minutes per part	$30.00	600 min.	Dispense mask and cure*	$15.00	300 min.
Remove wax after acid cleaning Place in hot water bath Labor: 1 minute per part Cycle: 30 minutes per batch	$1.00 ---	20 min. 30 min.	---	---	---
Rinse and dry Labor: 1 minute per part Cycle: 15 minutes per batch	$1.00 ---	20 min. 15 min.	---	---	---
Reapply wax for grinding	$30.00	600 min.	---	---	---
Remove wax Place in hot water bath Labor: 1 minute per part Cycle: 30 minutes per batch	$1.00 ---	20 min. 30 min.	Burn-off during existing heat treat operation	$0.00	---
Rinse and dry Labor: 1 minute per part Cycle: 15 minutes per batch	$1.00 ---	20 min. 15 min.	---	---	---
SUBTOTAL	$67.50	1410 min.	SUBTOTAL	$39.50	300 min.
Scrap: 0.5% amortized per unit	$12.50	---	Scrap: 0%	$0.00	---
TOTAL	$80.00	1410 min.	TOTAL	$39.50	300 min.
Equipment	---		Equipment (Curing Lamp)	$2,500.00	

*Cost of labor for both processes calculated at $60/hour

These reductions transform into a process cost savings of $40.50 per unit, a 50% reduction. Most astounding is that the 20 piece batches can be masked in less than one quarter of the time, saving nearly one hour per piece. This permits faster turnaround for overhaul programs and higher throughput for new component productions. From the magnitude of these cost savings, the added capital investment for one light-curing lamp ($2,500) can easily be recovered in less than one month.

The second example (Table 2) compares conventional tape masking to masking with a peelable light-curable maskant for a plating application. The example in Table 2 again reveals a major cost reduction of $34.50 per unit (49% reduction), resulting from labor saving and the elimination of rework/scrap associated with the tape masking process. The added cost of equipment for the UV process is easily recovered in less than one month.

Conclusion

In today's environment, process cost reduction has taken on a greater meaning – survival. Competitive pressures in the market are forcing manufacturers to evaluate every aspect of their processes for cost reduction opportunities. However, age old operations such as masking, are taken for granted and not targeted for improvement.

Alternative masking methods such as light-curable maskants open the door to savings never before possible. Labor costs can be cut in half, scrap eliminated, and overall component processing time reduced by as much as 60-70%. In addition to cost cutting opportunities, light-curable maskants improve the quality of the environment in the workplace, removing health hazards and reducing risk of operator injury. Benefits of this nature can lead to improved employee morale, which contributes to higher productivity.

A very positive case has been built for today's light-curable masking technology. Undoubtedly, more and more masking applications suitable for light-curable masks will be identified. The one constant that will continue to drive these applications will be cost reduction and improved productivity in the workplace.

Table 2. Cost Comparison – Traditional Tape Masking Versus a Light-Curable Peelable Maskant

TAPE			UV PEELABLE MASK		
	Cost Per Unit	Cycle Time Per 20 Pc.		Cost Per Unit	Cycle Time Per 20 pc.
One half roll tape at $30/roll	$15.00	---	Light-curable mask (0.33 lb. at $75/lb.)	$24.50	----
Apply tape 30 minutes per piece	$30.00*	600 min.	Apply Mask Spray: Labor 1 min. Cure: Labor 1 min.	$1.00 $1.00	20 min. 20 min.
Remove tape	$10.00	10 min.	Peel Mask	$10.00	10 min.
Wash and dry (tape residue) Labor: 1 minute per part Cycle: 15 minutes per batch	$1.00 ---	20 min. 15 min.	---	---	---
Rework: 0.5%	$12.50	60 min.	Rework: 0.0%	$0.00	---
SUBTOTAL	$68.50	705 min.	SUBTOTAL	$36.50	50 min.
Scrap: 0.1%	$2.50	---	Scrap: 0.0%	$0.00	---
TOTAL	$71.00	705 min.	TOTAL	$36.50	50 min.
Equipment	---		Equipment: UV Lamp Hand Sprayer	$2,500.00 $1,500.00	

*Cost of labor for both processes calculated at $60/hour

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