BETTER SOLUTION FOR AN OLD PROBLEM
UV Curable Masking Resins for Surface Treatment Applications

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Now, there is a better solution to this old problem of scrap and rework caused by unreliable masking. A family of solvent-free, UV curable temporary masking resins has been developed to simplify component masking processes prior to surface preparation and finishing operations. These resins cure in seconds under UV light and provide superior protection during 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 traditional masking products such as waxes, tapes, lacquers and other slow-curing, solvent-based maskants. This improved technology provides substantial cost savings through reductions in labor, rework and scrap. The UV masking resins are available in several viscosities and can be applied by spraying, dipping or brushing. Methods of resin removal include incineration, peeling or dissolving in water.

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INTRODUCTION

What is masking and why it is necessary?
Masks act as a self-sacrificing barrier for surface protection. Masking component features is an essential element of most surface finishing and enhancement processes. This protective barrier is necessary whether for grinding, abrasive cleaning, such as grit blast or vibratory finishing, acid stripping, shot peening, anodizing, chemical milling, plasma spray, or plating. The concept of protecting a surface with a masking may appear simple enough, but after thorough review and analysis, it becomes very apparent that masking can add significant costs to any operation. These costs may not be clearly visible at first, as the masking material is traditionally low in cost and not the major contributing element to the overall cost of the task. Rather, it is the actual masking process itself, more specifically the labor to apply and remove the masking from the component feature, which can be the most significant cost factor. The more complex and intricate a component is, the longer it takes to apply and remove traditional masks such as tapes, waxes, and solvent-based lacquers. In addition to the application of the mask, there are other hidden costs associated with using these masks. These costs can include scrap, component rework, production bottlenecks, specialized ventilation, valuable manufacturing floor space allocated to drying areas, workman's compensation claims, hazardous waste disposal costs and higher insurance premiums. Factoring in the cost of labor with the other hidden costs, it becomes evident that simply using a lower-priced masking material will not provide the sought-after cost savings which are essential to maintain a competitive position in the market.

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

Now, there is a better solution to this old problem of high costs associated with unreliable masking. The door must be opened to new technology. Such technology is currently available with a family of solvent-free, UV curable temporary masking resins developed to simplify component masking processes prior to surface preparation and finishing operations.

The new technology for Ultraviolet (UV) Curable Masking Resins was derived from UV Curable Aerobic Acrylic Adhesives and Coatings. Early in the 1980s these products were commercially available. The Aerobic Acrylic Adhesives and Coatings provided new efficiencies to manufacturers, resulting in millions of dollars in cost savings. Significant contributions to the cost savings include:

- **Increased Throughput.** UV Curable Aerobic Acrylics cure in seconds instead of hours thus eliminating bottlenecks and resulting in significant productivity gains.

- **Minimal Capital Investment.** UV Curable Aerobic Acrylic Adhesives and Coatings are cured with lamps which produce ultraviolet energy. A wide variety of lamps are available at moderate cost. The capital investment in an average UV curing system is typically recovered in the first year of operation, or sooner.

- **Simple Integration for Automated Production.** UV Curable Aerobic Acrylic Adhesives can be dispensed in a variety of ways, from a very defined bead line to dipping, spraying, pad printing or screen printing. UV curing lamps are easily placed into existing production lines, utilizing minimal space for curing.

SECTION 1. - UV CURABLE MASKING RESINS

UV Curable Masking Resins were first introduced in the mid 1990s; these new masking products have the potential to provide cost reductions similar to, if not greater than, the UV Curable Aerobic Acrylic Adhesives in the current turbine (aerospace and power generation), metal finishing and surface finishing industries. UV Masking Resins can be applied and cured in seconds, thus providing uninterrupted component processing. UV Masking Resins are available in several viscosity variations, from the consistency of water to non-flowing gels, to accommodate a wide range of application parameters. This range of viscosities permits controlled coverage of the masking resins, including coating thickness in a single application. UV Curable Masking Resins can be easily dispensed, both in manual and in fully-automated processing lines. Semi-automated or automated systems that provide controlled application of the UV curable, liquid masking resin can replace conventional, labor-intensive masking methods. The exceptional adhesion and superior resiliency of UV Curable Masking Resins can also improve component quality by reducing or eliminating the need for post-processing rework and scrap resulting from the deficiencies in traditional masking methods and products. It is possible to mask only one time for multiple surface processing operations with the use of these durable UV Curable Masks, thus eliminating stripping and remasking between processes. This increased efficiency results in lower costs.

SECTION 2. - CURRENT MASKING METHODS

The traditional masking products used today for surface protection are lacquers, tapes, waxes, and reusable boots, caps and plugs.

Lacquers

Typical lacquers used for masking during chemical processes are solvent-based and require a prescribed curing time to allow the solvent to evaporate and the remaining mask to cure, or harden, on the components. This curing process requires the masked components to be stacked or racked and left undisturbed for several minutes to several hours. Valuable production floor space is consumed during the evaporation of the solvents and curing of the components and creating a bottleneck. 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. 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. The U.S. Environmental Protection Agency mandates 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 initiated executive mandates that solvents be phased out of their facilities as soon as possible. Some water-based lacquers have been introduced to overcome the solvent issues. The drawbacks with these products are that they do not present 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, for the most part, watery, low-viscosity products. To achieve adequate protection as a mask, it may be necessary to repeat the application and cure processes several times to build the proper mask thickness. Multiple masking cycles create delays and add cost to the component manufacturing process.

The final step in the masking process is to remove the lacquer, which can be a difficult process. The lacquer-masked components are warmed, and then soaked in a solvent such as acetone. The majority of the lacquer mask slumps off the components, but some patches remain on intricate and complex features of the component and in cavities. Additional labor may be necessary to remove the lacquer remnants through subsequent processes involving brushing, grinding or burning.

Tapes
Masking tapes range in composition from the simple, low-cost paper tapes typically associated with painting, to the 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. For some applications, manufacturers procure tape in die-cut shapes, but this can be costly and is usually limited to high-volume production of a single component configuration.

Masking with tape is 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, lifting and wear. It is not uncommon for an operator to spend up to 8 hours masking a single intricate component.

The application of the tape, in addition to being time consuming, can also present 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 production time, workman's compensation claims and higher insurance premiums.

Finally, the removal of the tape is simple enough but the tape can leave a residue which will require additional labor costs associated with the cleaning to remove this residue.

Waxes
Wax is one of the least-expensive materials that can be used for masking, yet it is the most difficult to work with. The wax must be heated above its melting point to apply – 65°C (150^{o}F) or higher. The heating process requires special handling equipment and thermal energy, which can generate a surprisingly high utility cost. Operators also face the handling issues of the hot wax and the possibility of burns. Typically, wax is poured into components to protect internal cavities. Parts with tight dimensions and serpentine pattern cavities must be pre-heated to allow the wax to properly flow into entire internal cavities. Dipping is the only practical method to coat external surfaces of components, because hot wax cannot be applied in a controlled fashion.

Removal of wax requires the same melting process as used to apply the wax, with the exception that the component must now be heated with the wax. Again, operators must take precautions to avoid injuries or burns from the wax and the heated component. 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 frequently changed 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. Often, an additional cleaning operation is required after the wax removal bath. 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 its usage in high-temperature surface treatment processes such as acid cleaning, plating, and deposition coating. In addition, wax is soft which limits its usage in blasting applications. Precautions must be taken during handling to prevent accidental damage to the coating, which could result in rework and possible scrap.

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

SECTION 3. - THE NEW MASKING TECHNOLOGY: UV CURABLE MASKING RESINS

UV Curable Masking Resins are low-odor, non-flammable, liquid resins that cure in seconds upon exposure to 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, or other compounds, which can alter properties of the surface or the finish where the resin is being applied. Once cured, these masks can be handled like any industrial plastic. When removed from the component by the recommended methods, UV Curable Masking Resins leave no residue behind.

Uncured UV Masking Resins possess a high degree of stability which permits long shelf life (up to a year) when stored under ambient conditions 10–32°C (50-90^{o}F). Refrigeration of the product is not required. These resins are single-component products, eliminating the need to measure and mix prior to use. The UV Curable Masking Resins are available in a variety of containers to accommodate any dispensing system, ranging from small machine-ready syringes to bulk packaging measured by volume or weight.

UV masking resins are typically comprised of five basic elements:

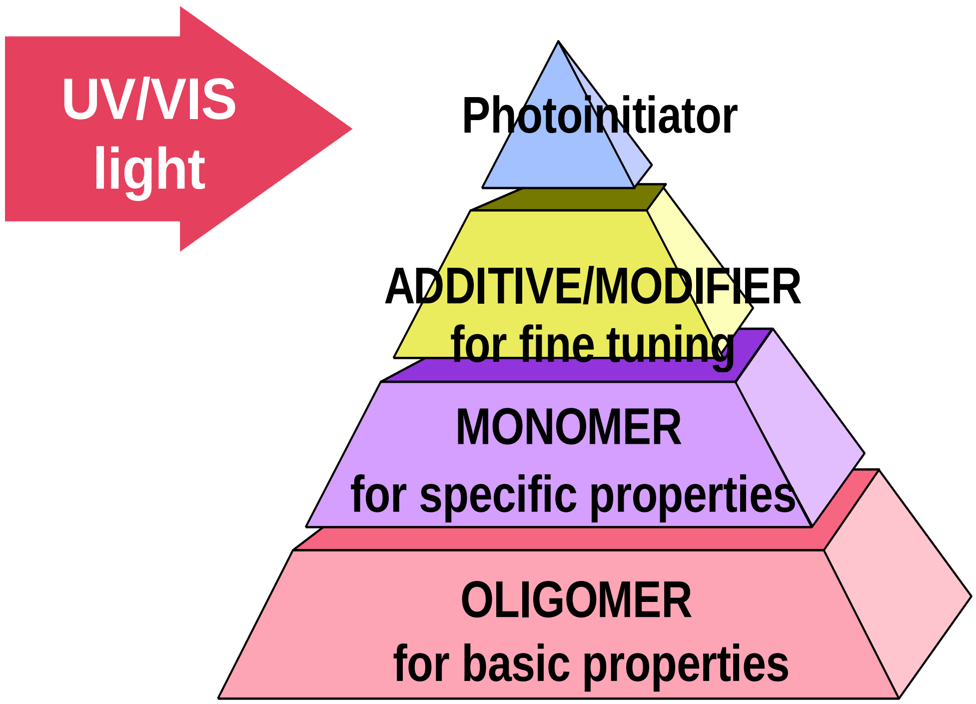

Figure 1. Typical Light Curing Urethane Acrylate Adhesive

Photoinitiator – This component of the UV Masking Resin initiates the start of the curing (polymerization) process when exposed to UV/Visible light energy of a compatible wavelength. In dual-curing resins, a secondary initiator may also be included which utilizes heat to begin polymerization for areas where UV light cannot reach and fully cure the masking resin, such as core cavities.

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

Modifiers – This component of the UV Masking Resin contributes to the durability by improving impact and crack resistance of the resin.

Monomers – Single units of polymers provide the adhesion characteristic to surface materials such as titanium, aluminum, iron, and nickel or cobalt based superalloys.

Oligomers – Oligomers are the backbone of the resin providing the basic properties of the UV Masking Resin such as hardness, elongation, and chemical resistance.

How Do UV Curable Masks Work?
The UV light curing process begins when the photoinitiator in the mask is exposed to the light energy source of the proper spectral output. The molecules of the resin split into free radicals (initiation), which then commence to form polymer chains with the monomers, oligomers, and other ingredients (propagation), until all of the ingredients have formed a solid polymer (termination). (See Figure 2). What was once a liquid resin is now a solid mask.

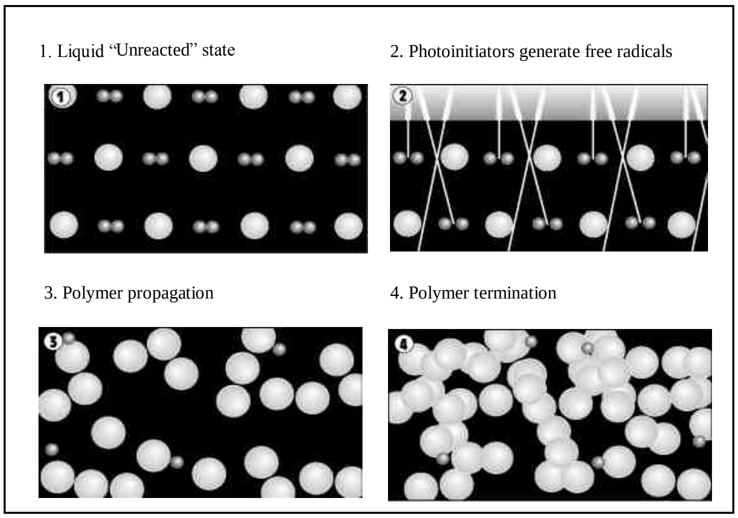

Figure 2. UV Light Cure Process

UV Curing Systems
The ultraviolet light energy source is critical to the UV mask curing process. UV curing lamps and systems of various configurations and styles 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.

UV curing lamps may be grouped into two very broad categories – spot lamps and flood lamps. UV spot lamps generate higher-intensity UV energy that is directed through a fiber or liquid-filled light guide, typically 5-8 mm in diameter. Spot lamp units are ideal for curing UV Masking Resins in cooling holes, sealing airfoil leading or trailing edges 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. The flood lamps are available as stationary stand-alone units or as a component of a conveyor for semi-automated production. This permits continuous in-line processing of components without delays.

Once the curing process has been established for a masked component, it cannot be varied without requalifying the process. This ensures complete cure of the UV masking resin each and every time, which is essential for achieving reliable and repeatable protection of the masked surface. The best source for assistance in selecting a curing system and qualifying a curing process is the manufacturer of the UV Masking Resin. Their expertise with UV Masking Resins and UV curing systems can help to implement a complete system to support the UV masking process with minimal time and expense.

SECTION 4. - WHAT DIFFERENT TYPES OF UV CURABLE MASKING RESINS ARE AVAILABLE?

There are three basic grades of UV masking resins which are grouped by their removal mechanism: burn-off, peelable, or water-soluble.

Burn-Off Masking Resins

The Burn-off Masking Resins grades typically present the best surface adhesion while providing the greatest resistance to heat and aggressive chemical solutions such as acid/alkali baths. For masking areas where UV light cannot penetrate, some burn-off grades masking resins also offer a secondary heat-curing capability. The heat-curable grades can be used for sealing core cavity to protect from debris, acid stripping, plating baths, and laser burn-through during drilling operations. Surface curing with UV light may take 20-30 seconds under a flood lamp, while heat curing may require 30-45 minutes in a 150°C (300°F) oven. Cure times can be slightly higher or lower based on the volume of maskant applied and the 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 540°C and 760°C (1000°F and 1400°F). Normally, the higher the temperature of the furnace the shorter the bake/incineration cycle will be. However, duration of the bake cycle must be qualified for each specific series of masked components. Many variables will influence the duration of time required to incinerate the mask. These variables are volume of mask applied, location of the mask (surface or core cavity), and thermal conductivity of the component. Thinly-coated surfaces can achieve complete burn-off in as little as 15 minutes. It is recommended to have a bake cycle of a one hour or slightly more for features with more masking resin such as core cavities, cooling holes, or a thickly-coated surface.

Burn-off masks are limited to parts that can tolerate high heat, such as the "hot section" components of a turbine engine. In many cases, a subsequent 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 UV Curable Mask allows it to completely combust and be exhausted from the furnace. And, the metallurgy of the heat-treated component remains unaffected by the UV Curable Mask.

A combustion study was conducted on a family of burn-off grade UV Curable Masking Resins 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 (UV Masking Resins). The finding from the study and subsequent report concluded that combustion of these UV Curable Masking Resins creates fume gases, which do not pose any risk in the workplace. In fact, combustion fume gases from this family of UV Masking Resins were likened to those fume gases generated through combustion of other organic materials, including natural polymers such as beechwood.

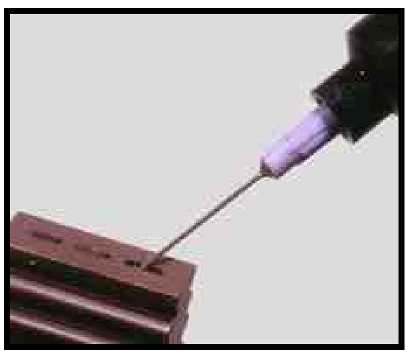

Figure 3. Core filling with a Burn-Off Masking Resin

Peelable Masking Resins

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

Peelable UV Masks are removed by simply prying up an edge manually or with the help of a non-abrasive tool, then pulling. The elasticity and flexibility of the material typically permits fast removal of the mask in one piece rather than in fractured segments. The surface is residue free after the mask is removed. The peeling process is made even easier by warming the cured mask to 60-85°C (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.

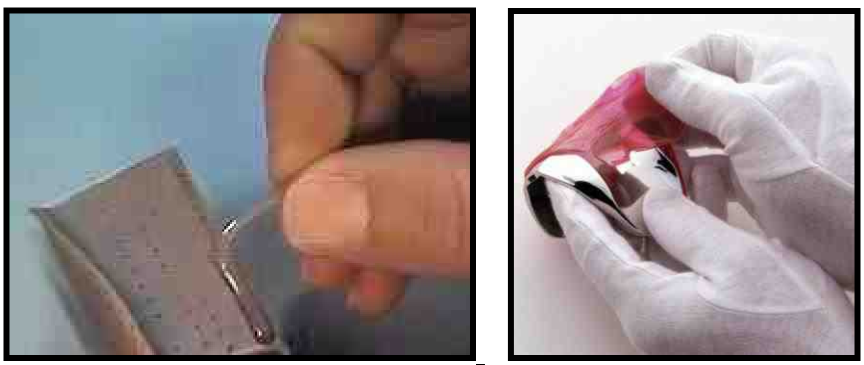

Figure 4. Removal of a Peelable Masking Resin

Water Soluble Masking Resins

Water soluble UV Curable Masking Resins provide excellent protection against the harsh media and aggressive blasts from "dry" finishing processes such as grit blasting, grinding, shot peening, and plasma spraying (Figure 5). The Water Soluble Resins can be applied using the same methods as the peelable grades. However, the truly significant difference 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 60-85°C (140-180°F) and a spray wash or agitated/ultrasonic bath. The agitation of the heated water speeds up the removal process. The mask completely dissolves in the water leaving no residue on the component surface.

It is recommended to utilize a closed-loop aqueous cleaning system for the water soluble mask removal. These systems are typically 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 UV Masking Resin does not contain any organic or inorganic toxic substances according to EPA, Connecticut, California, and Michigan Waste Discharge Listings. UV Curable Water Soluble Masking Resins dissolved in water exhibit a neutral pH of 7 in up to 20% concentration and do not create a handling hazard to operators.

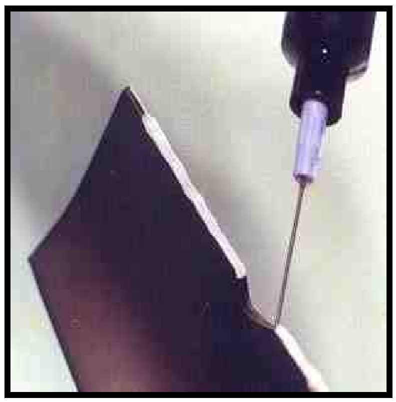

Figure 5. Sealing with a Water Soluble Masking Resin

SECTION 5. - COST BENEFITS OF UV CURABLE RESINS

How much can really be saved?

Much emphasis has been placed on the cost savings that result from the use of UV Curable Masking Resins. Some savings are direct and easily calculable while 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 UV masking process can bring actual cost savings into clear focus. Below, in *Table 1*, a comparison is made between two masking methods: a solvent-based lacquer along with wax to seal off the inner core and a burn-off grade UV masking resin. The surface treatment application comprises of grit blast and acid stripping of a turbine component. The inner core of the component is being masked off to protect it from debris entering and from the acid bath etching the surface. The wax process requires filling the core through a series of cooling holes followed by multiple coatings of a solvent-based lacquer on a portion of the component for surface protection against the acid bath.

The UV method utilizes a high-viscosity UV Masking resin, permitting the operator to seal all the holes and coat the external surfaces with the same mask. After all surfaces are masked, the components are placed in a rotating curing system which has multiple chambers. Throughput for the grit blast and acid stripping operations averages 500 units per week. Processed components are valued at $2,000 each.

Table 1. Cost Analysis Comparison
Wax/ Lacquer Mask versus UV Masking Resin

WAX AND LACQUER			**UV MASKING RESIN**		
	Cost Per Unit	Total Time Per 20 Pc.		Cost Per Unit	Total Time Per 20 Pc.
Wax (.75 lb @ $3.40/lb)	$2.50	---	UV Mask (.018 lb @ $72/lb)	$1.30	---
Lacquer ($30 per gallon) 96 coats per gallon (3 coats/part)	$1.00				
Warm parts in oven Labor*: 1 minute each Cycle: 20 minutes per batch	 $1.00 ---	 20 min. 20 min.	---	---	---
Apply Wax for acid stripping Labor: 4 minutes per part Cooling of hot wax before coat	$4.00	80 min. 15 min.	Dispense UV Mask and Cure*	$3.00	60 min.
Apply 1st coat of lacquer Labor : 3 minutes each	 $3.00	 60 min.	---	---	---
Cure lacquer in bake cycle Load parts in oven – 30 sec. each Cycle: 15 minutes per batch	 $0.50	 10 min. 15 min.	---	---	---
Apply 2nd coat of lacquer Labor : 3 minutes each	 $3.00	 60 min.	---	---	---
Cure lacquer in bake cycle Load parts in oven – 30 sec. each Cycle: 15 minutes per batch	 $0.50	 10 min. 15 min.			---
Apply 3rd coat of lacquer Labor : 3 minutes each	 $3.00	 60 min.			
Cure lacquer in bake cycle Load parts in oven – 30 sec. each Cycle: 15 minutes per batch	 $0.50	 10 min. 15 min.			
Burn-off during existing Heat Treat operation	$0.00		Burn-off during existing Heat Treat operation	$0.00	---
SUBTOTAL	**$19.00**	**390 min.**	**SUBTOTAL**	**$4.30**	**60 min.**
Scrap: 0.5% amortized per unit	$10.00	---	Scrap: 0%	$0.00	---
TOTAL	**$29.00**	**390 min.**	**TOTAL**	**$4.30**	**60 min.**
Equipment	---		Equipment (Automated UV Curing System and Spray System)	**$27,500**	
**Cost of labor for both processes figured at $60/hour*					

In the example in Table 1, the switch to the use of the UV Curable Masking Resins reduces or eliminates many cost elements from the Wax and Lacquer process. Because of the controlled viscosity, less material is used. Scrap is reduced from 0.5% to zero. Whether the component is a turbine component or an orthopaedic implant, the values range from several hundred to many thousands of dollars in value; the reduction in scrap alone is a significant factor. These reductions transform into a process cost savings of $24.00 per unit, over an 80% reduction. The time savings resulting from this switch is nearly 15 minutes per piece. This change in masking method permits faster turnaround for overhaul programs and higher throughput for new component manufacturing. From the magnitude of these cost savings, the added capital investment for the UV curing system and dispensing ($27,500) can easily be recovered in a very short period – in fact, less than a month in this case. Typically, the capital investment is recovered in less than one year.

SECTION 6. - CONCLUSIONS

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. Now, there is a better solution to an old problem of scrap and rework caused by unreliable masking.

Alternative masking methods such as UV curable temporary masking resins have been developed to simplify component masking processes prior to surface preparation and finishing operations. This new alternative masking option, UV Curable Masking Resins, opens the door to savings never before possible. Masking labor costs can be reduced, if not cut in half, scrap can be eliminated and overall component processing time reduced by as much as 60-70%. In addition to cost-cutting opportunities, UV Curable Masking Resins 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 UV Curable Masking Resin Technology. Undoubtedly, more and more masking applications suitable for UV 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. UV Curable Masking is a better solution for an old problem.

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GLOSSARY

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 UV Masking Resin 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 superalloys.

Oligomers – Oligomers are the backbone of the resin and are comprised of medium-length polymer units, which provide the basic properties of the UV Masking Resin such as hardness, elongation, and chemical resistance.

Photoinitiator (P.I.) – Component of the UV Masking Resin 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 for areas where UV light cannot reach and fully cure the masking resin, such as core cavities.

Polymers – Polymers are large molecules consisting of repeated chemical units (`mers') joined together, usually in a line, like beads on a string.

Ultraviolet Light – Ultraviolet (UV) light has shorter wavelengths than visible light. Though these waves are invisible to the human eye, some insects, like bumblebees, can see them!