AN ALTERNATIVE TO CHLORINATED SOLVENTS FOR CLEANING METAL PARTS

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INTRODUCTION

Chlorinated solvents such as 1,1,1-trichloroethane (TCA), 1,1,2-1,2,2-trichlorotrifluoroethane(CFC-113), and trichloroethylene (TCE) have been used successfully for many years for cleaning metal surfaces after machining and before assembly operations. Many choices concerning materials and process chemicals have been based at least partially on their compatibility with these solvents. However, TCA and CFC-113 are being phased out under the Montreal Protocol and the U. S. Clean Air Act Ammendments of 1990, and will not be available after December 31, 1995. The Clean Air Act also requires labels to be placed on products manufactured with the use of these solvents after May 15, 1993. TCE is not being phased out as yet, but is one of the solvents named in the US Environmental Protection Agency's 33/50 program. The goal of this voluntary program is to reduce the emissions of toxic substances. Obviously, alternatives are needed immediately.

The most feasible alternatives include changing the process to eliminate the cleaning steps, changing to a solvent-free cleaning process, or finding a solvent replacement. There are few alternatives for parts that must be cleaned, but cannot be exposed to water. None are perfect drop-in replacements; all require process changes. This article covers the feasibility of one of these alternatives, ethyl lactate.

Ethyl lactate is an organic solvent. It is the ethyl ester of natural L(+) lactic acid, which is produced by fermentation of sugar. It is approved by the U. S. Federal Drug Administration (FDA) for use as a food additive and is biodegradable, with a biochemical oxygen demand (BOD) of 0.7 pounds of oxygen per pound of ethyl lactate. The solvent is a clear, colorless liquid with a mild odor. It is completely miscible with water and most organic solvents.[1] It has no ozone depletion potential and is not a greenhouse warming chemical. It is, however, a volatile organic carbon (VOC). The flash point of the solvent is 52 °C. The ethyl lactate used in this study was supplied by PURAC America, Inc. The purer of two available solvent grades, PURASOLV® ELECT, was used for all experiments.

The purpose of this study was to test the feasibility of using ethyl lactate as a cleaning agent for metal surfaces. This involved testing the solvent's effectiveness at contaminant removal and its compatibility with the surfaces being cleaned.

CONTAMINANT REMOVAL

In order to be useful for surface cleaning, the solvent must be able to remove contaminants without damaging the parts. The first step was to test the cleaning efficiency of the solvent. Test coupons were loaded with known quantities of contaminants and cleaned with ethyl lactate in an ultrasonic tank. Nine contaminants were chosen for testing, representing a wide range of common cleaning problems. Skin oils, cutting fluids, coolants, mold releases and marking inks are all commonly used materials that must be removed. The contaminants, their uses and sources are listed in Table 1.

Table 1. Contaminants Used in Cleaning Efficiency Tests

Contaminant/Source	Function
Skin oil Volunteers	Contaminant
Tap Magic™ #1 Steco Corp., Little Rock, AR	Cutting fluid
Synthetic coolant, Model 6Z146 Dayton brand, W. W. Grainger, Inc., Chicago IL	Machining coolant
Dioctyl phthalate (DOP) Matheson, Coleman, and Bell, Norwood, OH	Plasticizer
Mineral oil E. R. Squibb & Sons, Inc., Princeton, NJ	Lubricant
Cocoa butter Woltra, West Orange, NJ	Lubricant
Real Ease® Borco Chemicals Inc., Bridgeview, IL	Silicone mold release
Lith-Ease® white lithium grease American Grease Stick Co., Muskegon, MI	Corrosion inhibiting grease
Dykem Steel Blue® Dykem Company, St. Louis, MO	Layout fluid/machining ink

One-inch diameter 304 stainless steel disks were used as test coupons. Depressions were made in the centers to position the liquid contaminants on the coupons. For each cleaning test, the coupons were weighed to the nearest 0.01 mg on a Perkin-Elmer electronic microbalance. A contaminant was applied to the surface of the coupon, and it was reweighed. Control coupons (no contaminants added) were used throughout the experiments. Contaminated coupons were dried in a cleanroom and then desiccated overnight to allow volatile materials to evaporate. This made the cleaning more difficult, providing a more stringent test of the ethyl lactate's cleaning capabilities. After the desiccation, the coupons were immersed in ethyl lactate and agitated with 40 kHz ultrasonics for 5 minutes, followed by a 30 second immersion in fresh solvent. All cleaning and rinsing steps were at room temperature. The parts were then dried again and reweighed. The removal efficiencies were calculated and listed for each of the contaminants in Table 2.

All contaminants were removed to levels below the detection limit for the microbalance. This equates to better than 99.9% cleaning efficiency by weight, even for the cutting fluid and the water soluble coolant.

Table 2. Removal of Contaminants from Stainless Steel

Contaminant	Average Contaminant Weight Before Cleaning (mg)	Average Contaminant Weight After Cleaning (mg)
Skin oil	0.46	0.00
Tap Magic™ cutting fluid	19.45	0.01
Synthetic coolant	39.02	0.02
Dioctyl phthalate	33.99	0.00
Mineral oil	32.32	0.00
Cocoa butter	58.54	0.00
Silicone mold release	23.16	0.00
White lithium grease	30.80	0.00
Dykem Steel Blue® layout fluid	3.16	0.00

EFFECT OF CONTAMINANT AGING

Contaminants generally become more difficult to remove as they dry and age. The next step in this project was to test ethyl lactate's effectiveness on contaminants that had been aged or baked onto the stainless steel surfaces. Two contaminants were used for these tests. Silicone mold release was chosen because it is known to be difficult to remove. Lithium grease was chosen because it is used as a corrosion inhibiting grease and is often left on parts for an extended period before cleaning.

Three types of aging were examined. They were: (1) overnight desiccation at room temperature, (2) 30 minutes in a vacuum oven at 50 °C and -15 in. Hg, and (3) long term desiccation (3 weeks) at room temperature. All tests were run in triplicate.

The contaminated stainless steel coupons were all cleaned by the same cleaning procedure as in the previous work, with the exception that a 5 minute overflow rinse in deionized water was substituted for the ethyl lactate rinse. The results are in Table 3.

The age and drying conditions of the contaminant had a small effect on the cleaning efficiency with the ethyl lactate. The samples held in the desiccator for 3 weeks did have slightly more contamination remaining on them after cleaning than the samples dried overnight. The samples heated in the vacuum oven were cleaned to nearly the same level as the overnight samples. Differences are within the range of experimental error.

Coupons with silicone mold release dried on them for 3 weeks were also cleaned at an elevated temperature (65 °C) with ultrasonic agitation and water overflow rinse. The cleaning efficiency for those coupons was higher than for room temperature cleaning (99.57%).

The ethyl lactate is a strong enough solvent that the age of these contaminants is not a major factor in the cleaning efficiency. Cleaning in warm solvent is more effective than in room temperature solvent on silicone mold release. For aged or difficult contamination, an elevated temperature clean may be beneficial.

Table 3. Effect of Contaminant Aging

Contaminant	Aging Process	Removal Efficiency, %
Lithium grease	Desiccate overnight	99.99
Lithium grease	Vacuum oven	99.94
Lithium grease	Three week desiccation	99.60
Silicone mold release	Desiccate overnight	99.86
Silicone mold release	Vacuum oven	99.83
Silicone mold release	Three week desiccation	99.12
Silicone mold release	Three week desiccation, 65°C solvent clean	99.57

COMPATIBILITY WITH METALS

Acidity

Upon exposure to moisture, ethyl lactate hydrolizes, causing an increase in the acidity of the solution. The acidities of the ethyl lactate samples were measured prior to being used in the immersion tests. Fresh solvent was measured immediately after opening the nitrogen purged container. A second sample was also tested, from a container that had been opened six months previously and stored at room temperature without nitrogen purge. The acidity was measured by titration and calculated as free lactic acid.

The product literature lists the maximum allowable acidity for the as-received solvent as 0.02% free lactic acid. The acid content of the fresh solvent was 0.01% (63 ppm), well below the allowed maximum. The acidity of the aged sample of the solvent was 0.10% (1010 ppm) as free lactic acid. This exceeds the specification and could have an effect on the compatibility of the solvent with metals immersed in it. Therefore, immersion tests were performed with both the fresh and aged solvent.

Immersion Tests

The last step in these feasibility studies was to investigate the compatibility of the ethyl lactate with selected metal alloys. Three alloys were chosen for these preliminary experiments: 6061 aluminum, 1018 carbon steel, and AZ91A magnesium. Coupons of each metal were stamped with identification numbers. The stamped side of each coupon was finished to 120 grit. The opposite side was finished to 600 grit. Each coupon had a hole through it at one end for handling. The coupons were transported by hooking the coupon through the hole with a stainless steel probe. The probe was used only to carry the coupon and was not immersed in the solvent.

All coupons were cleaned before starting the compatibility test with two minutes of ultrasonic agitation in a 50/50 solution of acetone and isopropanol followed by an isopropanol rinse. The coupons were allowed to dry in a Class 100 cleanroom and desiccated overnight.

Each coupon was weighed to the nearest 0.01 milligram. Length, width, and thickness were measured to the nearest 0.001 inch. Glass scintillation vials with Teflon™-lined caps were used to hold the coupons during the test. Twenty milliliters of fresh or aged ethyl lactate was added to each vial for 1, 8, or 24 hours immersion. The tests were run in triplicate, and control coupons were used for all tests.

After the specified immersion period, the coupons were removed from the solvent and hung to dry for 24 hours in a Class 100 cleanroom. Any change in the appearance of the solvent or the coupons upon removal from the ethyl lactate was noted.

After 24 hours, the coupons were weighed and measured. Changes in coupon weights or dimensions were calculated and recorded. Photomicrographs of selected metal coupons were taken to document changes in the appearances of any coupons.

The weights and dimensions of the metal coupons were virtually unchanged by the solvent immersion. No signs of corrosion or changes in the physical appearance were discernable on the aluminum coupons.

Visual inspection under 150x and 300x magnification did show some changes in the magnesium and steel coupons. Some magnesium coupons had a faint, white residue on the surface. Small pits were found in the surface of magnesium coupons exposed to the aged ethyl lactate and those exposed to the fresh solvent for 8 and 24 hours (Figure 1). The effects were greater with increased exposure time and with aged ethyl lactate. There were no signs of pitting on the samples exposed to the fresh solvent for one hour. Therefore, this solvent is not recommended for prolonged exposure to magnesium alloy AZ91A. The solvent may be suitable as a short-exposure cleaning agent and should be evaluated on a case-by-case basis.

Some of the carbon steel coupons developed small, light colored spots, similar to water spots. These were very faint and were visible only with magnification. Since the nonvolatile residue of the solvent was very low, it is unlikely that the spotting was due to residues from the solvent. It is more likely that there was some reaction of solvent with metal. On some coupons, residues were visible at the end of the coupon opposite from the hole. This is the same location as most of the residues on the magnesium alloy coupons. It is also the location on the coupon where the last drop of solvent dried on the hanging coupons. The spotting and residues were more noticeable with the aged solvent and longer exposure times.

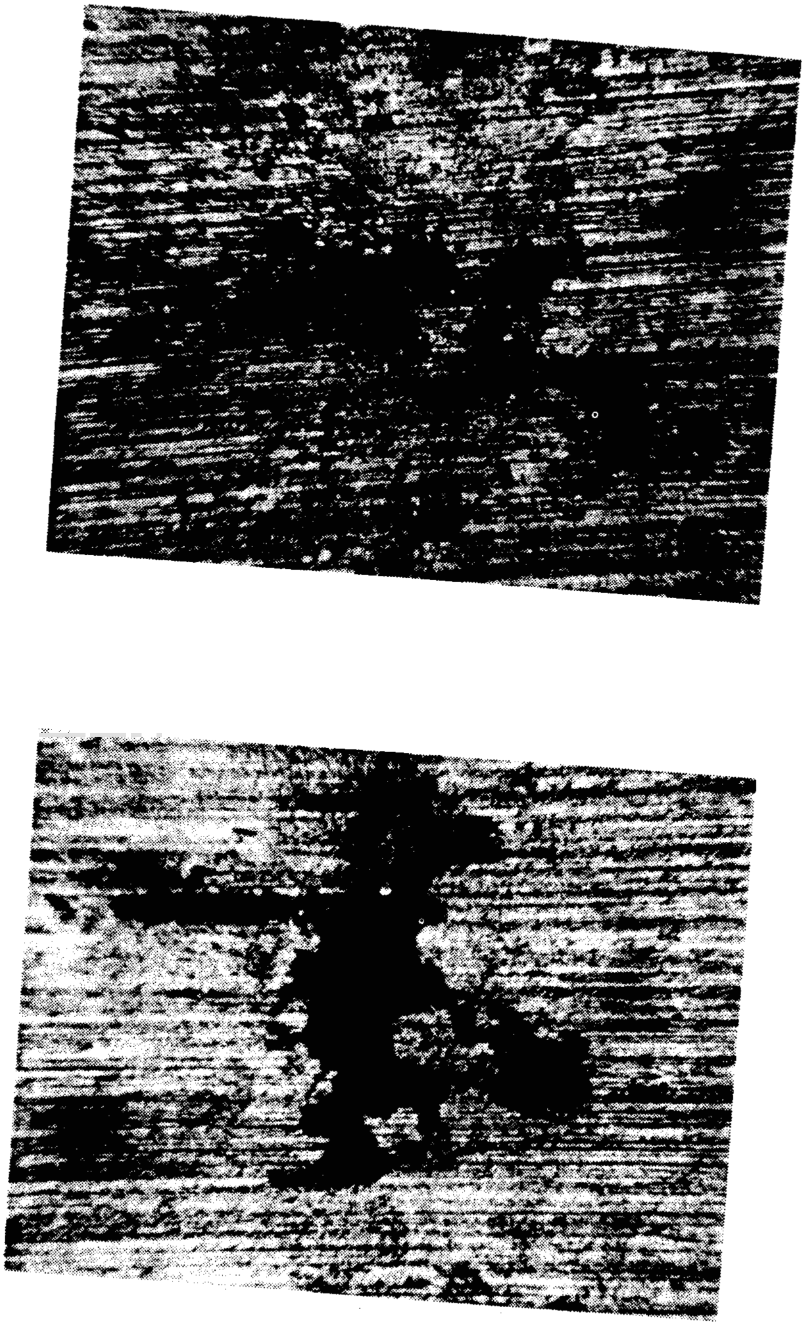

Figure 1. Pits etched in magnesium coupons soaked in ELECT 24 hours. Top = 150x magnification, Bottom = 300x magnification

CONCLUSIONS

Ethyl lactate is a viable alternative for replacement of chlorinated solvents for cleaning metal surfaces. It is effective in removing a wide range of contaminants of the types often left on parts during machining and assembly operations. The solvent does have some effect on magnesium and long immersions may affect carbon steel. One hour immersion had little effect. Fresh solvent has less of an effect on the metals tested than the six month old solvent. Prior to any process implementation, actual parts to be cleaned should be tested with the ethyl lactate to confirm effectiveness and compatibility.

REFERENCES

1. Product literature and material safety data sheets from PURAC America, Inc.

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