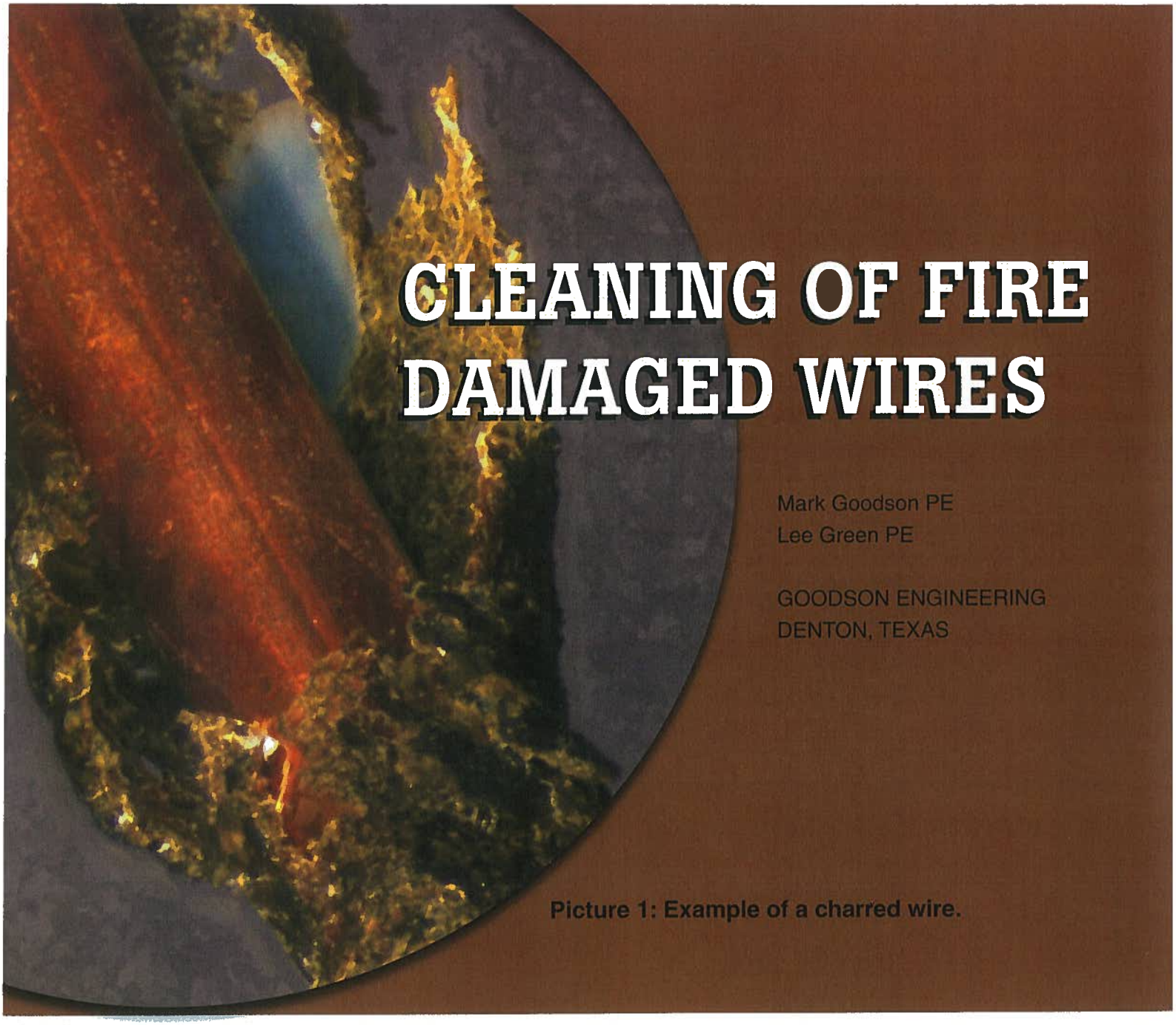

CLEANING OF FIRE DAMAGED WIRES

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Picture 1: Example of a charred wire.

The electrical engineer who is examining wiring after a fire has frequently been tasked with the cleaning of wires, such that wiring damage can be assessed. The writers have been to numerous labs, where various cleaning solutions have been used with ultrasonic agitation to try and clean a fire damaged wire; normally the techniques provide little improvement in clarity.

For this paper, we evaluate various techniques and comment on their efficacy. We also show by way of microscopic images the effect(s) that different methods of cleaning have on wiring. The scope of this paper will cover ultrasonic cleaning with solvents, dry ice cleaning, and plasma ashing.

EXPERIMENTAL SET-UP

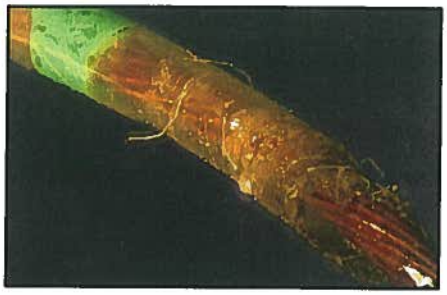
Lengths of solid and stranded wire, each 12 AWG, were subjected to heat from a propane torch until the insulation was heavily charred. Thereafter, we attempted to clean the wires using various techniques listed above.

CLEANING TECHNIQUES USED

The cleaning techniques used were often techniques we have seen used in other labs. As an example, we have seen one lab attempt to clean wires using isopropyl alcohol. For that reason, we included isopropyl alcohol as a solvent in our ultrasonic cleaning matrix.

1.) Ultrasonic cleaning by way of solvents

Ultrasonic baths make use of sound waves that are acoustically coupled to water or another solvent. The continued acoustic waves in the solvent cause agitation of the adulterants (in our case, the remains of pyrolyzed insulation). There may or may not also be chemical action, depending upon the solvent or surfactant that is used.



Picture 2: Example of a wire after ultrasonic cleaning. Note that much of the PVC char is gone, but the clear Nylon outer jacketing is still present.

A solvent is used to dissolve the pyrolyzed organic remains of the insulation. Not all liquids that we tried as solvents worked to truly clean or dissolve the insulation remains.

A surfactant (surface active agent) is used to act as a detergent. It acts to lower surface tension between water and oils, allowing them to become miscible. Soap is a form of a surfactant.

One agent often used in cleaning electric parts wires is known as Branson OR (Oxide Remover).[1] This is a detergent solution with a pH of 3.8. It has the ability to etch wires, and for this reason, we do not normally recommend its use unless it is carefully managed.

Picture 3, 4, and 5: Freshly stripped wire, etching after "Branson OR" soak, close-up view of "Branson OR" soaked wire.

In some cleaning processes, the cleaning efficacy can be increased by heating the bath. Per the rule of Arrhenius, each 10 degree C rise in temperature results in a doubling of reaction rate.

Some of the solvents we used in our work are toxic, and the reader is cautioned to refer to Materials Safety Data Sheets, MSDS's. One particular solvent NOT tested was 1, 1, 1 trichloroethane; it has been used by

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one of the authors (MEG), and it performs well in cleaning wires. Its use has now been phased out due to ozone depletion problems.

2.) Dry ice cleaning

Those familiar with chemistry know that dry ice sublimates – it has a phase transition from solid to gas. Dry ice cleaning makes use of what is essentially dry ice 'snow balls' approximately 1/8" in diameter. The pelting of the snow balls onto a wire removes the insulation and any foreign debris. The thermal shock and the sublimation cause the excess material to be dislodged from the copper. Youtube has an excellent demonstration of dry ice cleaning. [2]

Dry ice is non-toxic and can be handled quite easily without a fear of toxicity or disposal issues.

3.) Plasma cleaning / ashing

Plasma ashing makes use of a plasma cleaner / asher. In use, a wire specimen is placed in a vacuum chamber, and the chamber is evacuated until the vacuum is several millitorr. (A torr is 1/ 760 of an atmosphere). Thereafter, a Radio Frequency (RF) field, usually at 13.56 MHz is generated. Oxygen is introduced into the quartz chamber. Plasma is created, and the O2 molecules divide into O atoms. (Plasma is often called the fourth state of matter; lightning is a form of plasma. Generally, it is a hot gas that is ionized; there are separate positive and negative charges, but the net charge enclosed approximates zero.)

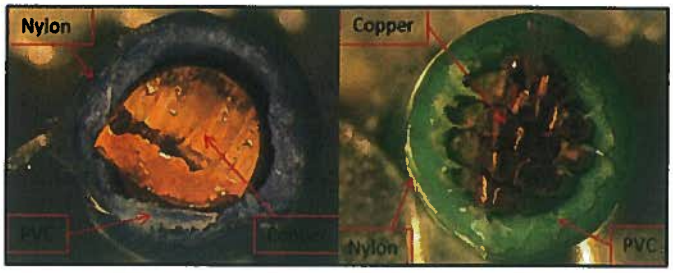
A common use of plasma ashing commercially is in processing semiconductor wafers, where it is necessary to remove organic photo resist without disturbing the intricate electronic circuitry. The monatomic oxygen is created under a vacuum and an electric field, and the oxygen combines with the photoresist to form ash. The ash is then removed by the vacuum pump.[3] A picture of a plasma asher is shown below.

Picture 6: Plasma asher

The reason that the authors tried plasma ashing is because it is a process that is intended for removing organics while operating at a low temperature. In that copper wiring is much more robust than electronic circuitry, we felt this may be an ideal technique for removing insulation remains without damaging the wire.

TESTING

For testing samples, we used 2" specimens of #12 solid wire, all with THHN insulation. This insulation scheme is commonly used for both wiring in commercial buildings and also in type NM (so called 'Romex'). This type of wire is constructed with an outer jacketing of Nylon. FTIR analysis showed that the jacketing is Nylon 6. The inner layer of insulation is PVC (Poly Vinyl Chloride), and also has plasticizers present.



Pictures 7 and 8: Solid and stranded conductors with insulation

The following instruments were used for our testing:

Hitachi S-3000 SEM with EDX
Nicolet 5700 FTIR
Leica MZ7.5 stereoscope with motorized zoom
Branson 3510 ultrasonic cleaner

We created test samples cutting small lengths of both solid and stranded copper wire and then burning the insulation by using a propane torch.

TECHNIQUES

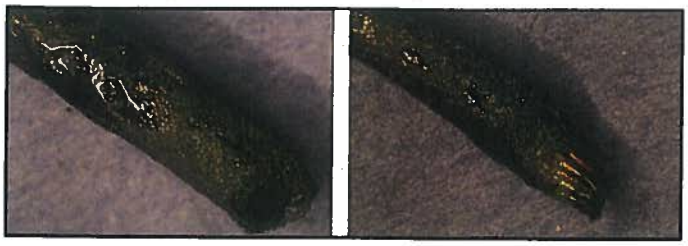
Dissolving

We selected various solvents and placed them, one by one, in a separate beaker with a set of burned wires. One wire was stranded copper wire and the other was a solid copper wire. We checked every 15 minutes to observe the progress. We recorded which solvents were effective and which were not. This testing was carried out at 23 deg C (73 deg F). We did not use ultrasonic energy for this first round of testing.

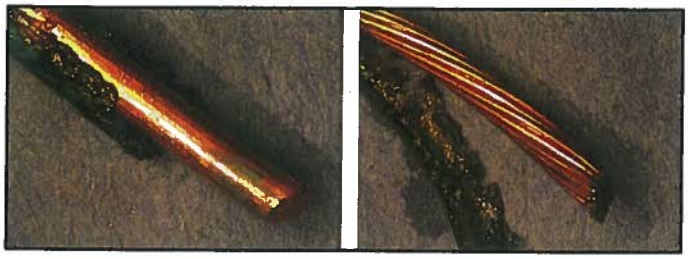
Ultrasonic Cleaning

After our first round of testing, the solvents that worked at room temperature were used in a second set of tests. This set of tests utilized the ultrasonic cleaner with the solvents heated to 71 deg C (160 deg F). The specimens were placed in the heated / agitated solutions for one hour. Our work in this second round of testing showed that DMSO (Dimethyl Sulfoxide) and MEK (Methyl Ethyl Ketone) yielded the greatest cleaning. In an attempt to improve the results further, we experimented with a combination of the two chemicals. After multiple samples and different ratios of the two were tested, it was determined by gross and microscopic observation that the optimal solution to remove burnt insulation from the wires was a 3:1 mix of DMSO to MEK, respectively. The following

microscopic photos show the deterioration of material after one hour of cleaning in the ultrasonic machine with 3:1 DMSO / MEK at a temperature of 71°C.



Pictures 10 and 11: Solid and stranded conductors before cleaning.



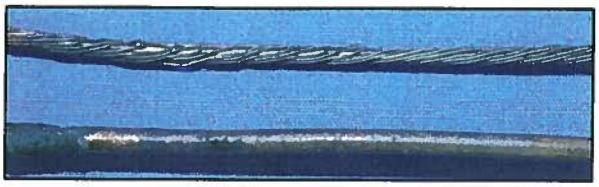
Pictures 12 and 13: Solid and stranded conductors after cleaning in a mix of 3:1 DMSO and MEK at 71 deg C after one hour in an ultrasonic cleaner.

The solvents used were those that are commonly available in an engineering setting. The enclosed table shows various solvents that we tested:

Solvent	Temp, deg C	Time	Results
Water	71	1 hr	No change
Simple Green	71	1 hr	No change
Ethanol	71	1 hr	Little deterioration
Methanol	71	1 hr	Little deterioration
Isopropyl alcohol	71	1 hr	Little Deterioration
Xylene	71	1 hr	Little Deterioration
MEK	71	1 hr	Deterioration of the pvc
Acetone	71	1 hr	Little Deterioration
Branson OR	71	1 hr	Deterioration and etching of copper
DMSO	71	1 hr	Significant Deterioration
Alconox	71	1 hr	No Significance
1:1DMSO w MEK	71	1 hr	Deterioration of PVC
1:2DMSO w MEK	71	1 hr	Deterioration of PVC
1:3DMSO w MEK	71	1 hr	Deterioration of PVC
2:1DMSO w MEK	71	1 hr	Deterioration of PVC
3:1DMSO w MEK	71	1 hr	Most Significant Deterioration of PVC

DRY ICE CLEANING

Samples, both solid and stranded, were sent to a dry ice blasting facility, one that specializes in cleaning of electrical parts. The dry ice blasting process worked well for the solid conductor, but did not do well with the stranded cable. As the pictures below show, the dry ice blasting deformed the wire strands in the stranded cable. The finish of the copper is also not shiny, which can make for a challenge when taking microscopic photos

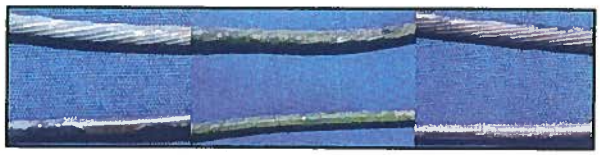


Picture 14: Photo of dry ice blasted wire, stranded and solid. Note damage to stranded conductors.

PLASMA CLEANING (ASHING)

Another set of samples, stranded and solid, was sent to a plasma cleaner manufacturer for plasma ashing. As with dry ice blasting, preparing and sending samples to an outside company is prohibitive given the time restraints of a typical lab examination. But as with dry ice blasting machines, plasma cleaning machines are also available for purchase. The facility that cleaned these samples used reactive ion etching and oxygen gas. This process took 8 hours to clean the wire of all insulation remains. A CF4 (Carbon Tetra Fluoride) gas could be used, and would cut the time in half but it is more aggressive and some of the important markers on the wire could be damaged. Moreover, CF4 exhaust must be carefully managed.

As with dry ice blasting, the plasma cleaning resulted in a flat appearance of the wire. To brighten up the wire, two combinations of secondary cleaning were used. A first set of wires was ultrasonically cleaned using an Alconox solution. The second set of wires was first cleaned with Alconox and then re-cleaned with Branson OR. See pictures below of plasma cleaned, plasma cleaning with secondary Alconox cleaning and finally plasma cleaning with secondary Alconox cleaning and tertiary Branson or cleaning.



Pictures 15, 16 and 17: Plasma cleaning followed by Alconox and then Branson OR, respectively.

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DISCUSSION

The astute chemist who is reading this paper will immediately spot the folly of some of the attempts at cleaning wires, particularly using ultrasonic methods. The 'folly' is that there is little 'science' put into the way that wires are cleaned. As an example, many investigators know that indoor fire sprinkler piping and underground irrigation piping is made from PVC, and they also know that PVC will not dissolve in water. So the question has to be asked as to why one would ultrasonically clean wires with PVC insulation in water.

We have seen most of the solvents from the ultrasonic protocol used at one lab or another. It is for this reason that we chose the solvents that we did. And similarly, while the surfactants (Simple Green, Alconox) are technically not solvents, they are none the less used in labs in attempts to remove charred insulation.

The heart of this discussion is that one must understand the chemistry associated with what is being attempted. We found excellent results in cleaning PVC wire with DMSO and MEK solutions, particularly at high temperatures. What is important to note is that some PVC wiring has outer nylon jacketing. The appropriate solvent for Nylon 6 is not MEK or DMSO; rather, trifluoroethanol (TFE) is often used. (The difficulty with TFE is that it is toxic to blood, upper respiratory system, brain, reproductive system, and eyes.[4])

What is also related to the chemistry is the fact that the thermal energy associated with a fire has probably already started the decomposition process. If the heat has not brought about damage to the insulation, it begs the question as to why the wire is of interest.

The reader is cautioned as to the need to refer to MSDS sheets on almost any chemical used, save tap water. Some of the chemicals can be dangerous if not handled appropriately. The reader should also note that there are many chemicals available as well as chemicals that have become unavailable due to health and environmental issues. Years ago, one of the writers on many occasions used 1, 1, 1 trichloroethane to dissolve organics off of metallic pieces. The difficulty now is that trichloroethane is unavailable because of ozone depletion issues.

CONCLUSIONS

There are multitudes of ways to clean wires, but for the purposes of fire investigations a chemical solution used in conjunction with an ultrasonic cleaner seems to be the most viable choice; however, the solvent use must be chosen so as to dissolve the plastic insulation that is present. Dry ice cleaning and plasma cleaning both require expensive machines. Dry ice cleaning doesn't fare well with stranded wires and could potentially damage the evidence. Plasma cleaning is effective, but takes a long time to achieve satisfactory results; as such, its use is not always viable for lab exams.

References

1. *Branson OR http://www.bransoncleaning.com/pdf/ORconcClgFormula.pdf*
2. *YouTube - http://www.youtube.com/watch?v=FP_mE4i9-3U*
3. *Plasma Cleaning http://www.p lasmaetchcom/?gclid=CN2Mkt6oxq0CFW-HtgodXirngg*
4. *http://www.sciencelab.com/msds.php?msdsId=9925323*

in the news

Will reckless conduct erode the reputation of fire services

By R. Kirk Hankins, IAAI-CFI, MIFireE

In 2010 the Cumberland Valley Volunteer Firemen's Association (CVVFA) recognized that reckless conduct was eroding the reputation of the fire service. While this inappropriate conduct was being conducted by a relatively small minority of the nation's fire service personnel, the potential for a negative impact on the entire profession was increasing.

The CVVFA released a white paper, Fire Service Reputation Management to address the unethical, immoral, inappropriate, criminal and other conduct that reflected poorly on the individual member, their departments, communities and the entire fire service. The white paper (available at www.cvvfa.org) addresses behaviors such as alcohol abuse, theft, firefighter arson and cheating on qualifying exams to name a few.

The International Association of Arson Investigators (IAAI) supports the initiatives contained in the white paper. The IAAI's Code of Ethics was adopted more than 50 years ago. We have been in the forefront on the issues addressed in the reputation management report.

As a result of the issues identified in the white paper, the National Volunteer Fire Council (NVFC) published a document, Report on the Firefighter Arson Problem: Context, Considerations & Best Practices (available at www.nvfc.org.) IAAI members participated in the development of that document. The Association has sponsored training courses on this subject at their Chapters' Regional and Annual Training Conferences over the past several years.

It has become fairly common to read news reports about individuals improperly taking funds from the treasury of their organizations. The IAAI has attempted to assist "for profit" and "not for profit" associations from internal theft and embezzlement. The IAAI developed and sponsored a training course, Who's Minding the Store, in an attempt to help these associations limit their exposure to internal theft. The course outlines best practices for accounting and suggests policies for accountability on the part of fund managers.

The Certified Fire Investigator (IAAI-CFI®) certification, Fire Investigator Technician (IAAI-FIT), Evidence Collection Technician (IAAI-ECT), and Certified Instructor (IAAI-CI) credentials are qualification exams offered by the IAAI. Of these, IAAI-CFI® certification is accredited through the Pro Board.

As an accredited agency, our membership in the Pro Board has helped to keep us abreast of the issues concerning cheating on qualifying examinations. Every year we receive training on this topic to include trends and methods that are being used. Cheating on exams includes not only the examinee but also extends to the examiners and sometimes the administrative officers.