LIGHTNING INDUCED CSST FIRES

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ABSTRACT

Corrugated Stainless Steel Tubing (CSST) represents a relatively new technology for delivering fuel gas within a residential or commercial structure. The main benefit of CSST is brought about by a savings in installation time, relative to black pipe. However, the flexible thin walls of CSST also present a problem in terms of the propensity of CSST to fail when exposed to electrical insult, particularly lightning. We outline here the some of the theoretical basis for CSST failures caused by lightning, as well as investigative techniques to be used when examining a fire scene.

INTRODUCTION TO CSST

Corrugated Stainless Steel Tubing (CSST) is a relatively new building product, and is used to plumb structures for fuel gas in lieu of conventional black pipe. The advantages that are offered include a lack of connections and a lack of threading - in essence, it is a material that results in substantial labor savings (relative to black pipe). CSST is recognized by ANSI / IAS LC-1 -1997[1]. CSST consists of stainless steel corrugated tubing that is sheathed by a polymer conformal coating. Each manufacturer seems to have a proprietary system for achieving couplings / connections, but in general, the CSST (in that it conforms to ANSI LC-1) can be thought of as a commodity.

The authors have investigated several fires wherein CSST has failed when damaged by lightning. We outline here the theoretical issues regarding CSST, as well as results of fires we have investigated.

CSST DEVELOPMENT

The introduction of CSST into the United States was brought about by a firm called Foster-Miller. This engineering firm developed CSST as an alternate to black pipe. Our own reading of various pieces of literature shows that the driving issue is one of economy[2]. However, we caution the reader to review the literature and draw his / her own conclusions. CSST is made by 6 manufacturers, and each manufacturer requires a potential installer to take a several hour installation course. The installation courses are required as part of ANSI LC-1, and are an attempt to insure only qualified installers make use of CSST[3]. This arrangement will likewise prevent CSST from being available at home improvement stores.

CSST was first recognized by the NFPA in the *Fuel Gas Code* (NFPA 54) in 1988[4]. The IAPMO finally approved CSST in 2003[5]. It is interesting to note that in 2000, the IAPMO rejected CSST for reasons of safety[6]. The Foster-Miller documentation submitted in 2000 to the IAPMO states that there had been 50 million feet of CSST installed without one reported failure[7]. Now that there have been numerous reported failures, IAPMO action on CSST will be of interest.

In analyzing CSST, it is important to note that we can find no evidence of testing for lightning resistance during product development. The NFPA has stated that when CSST was first considered in 1988, lightning was given no consideration[8].

CSST UTILIZATION

CSST is different from black pipe, in a number of ways. On a CSST system, gas enters a house at about 2 psi, and is dropped to ~ 7" WC by a regulator in the attic (we are assuming a natural gas system). The gas then enters a manifold and is distributed via 'home runs' to each separate appliance. Unlike black pipe, a CSST system requires one separate run for each appliance. (See Figure 1 for a typical manifold) As an example, a large furnace and 2 water heaters in a utility closet will require 3 separate CSST runs; with black pipe, the plumber may have just used 1 run of 1" pipe and then teed off in the utility room. The reality of this design is that now there is a tubing system carrying 2 psi of NG in part of the residence; in addition, the requirement of one home run per appliance increases dramatically the number of feet of piping in a building.

Figure 1: Manifold and regulator leads of CSST setup

CSST is sold in spools of hundreds of feet, and is cut to length in the field for each run. In this regard, CSST has no splices / joints behind walls that might fail. CSST can be identified by its bright yellow jacket. Test pressures are higher for CSST than black pipe, and the industry touts this as a selling point; we find this somewhat of a 'red herring'. We know of no need to increase the Factor of Safety (FS) for black pipe – pipe tested at 20 psi and carrying 7" WC has provided satisfactory services for years. CSST does offer an advantage over black pipe in terms of structural shifts; with black pipe systems, the accommodations for vibrations and / or structural shifts are handled by appliance connectors.

THEORETICAL CALCULATIONS

CSST is extremely thin, with walls typically less than 10 mils in thickness. This lack of mass, necessitated by the desire for easy routing of the tubing, has resulted in a material that is easily punched through by electricity. Once the tubing has been perforated, it is possible for the escaping gas to be ignited by the metallic by-products of the arcing process, by auto-ignition, or by adjacent open flames.

The theoretical energy level required to melt a specimen can be compared by using both heat capacity and melting temperature. The heat capacity is the amount of heat needed to raise the temperature of either sample one degree Celsius. Changing the temperature from an initial temperature to the melting temperature requires the heat capacity to equal:

$$q = C \cdot m \cdot \Delta T_m + m \cdot H_f \qquad [1]$$

where C is the specific heat, H_f is the heat of fusion, m is the mass of the specimen, and ΔT_m is the change in temperature from the initial temperature to the melting temperature.

Our own field data indicates that lightning damage to black pipe is sometimes so small that it is often only visible with microscopic analysis and limited to a small pit that does not leak; lightning strikes involving CSST create leaks that vary from pinhead size to almost ¼" 'orifices.' For comparison sake we show the heat capacity for equivalent sized holes in specimens of black iron, CSST, aluminum, and copper tubing. Table 1 lists the relevant properties for all four samples.

TABLE 1

Material	C (BTU/lb F)	T_m (^oF)	H_f BTU/lb	Density (lb/in^3)	Wall thickness (in)
CSST (304) ½" OD	0.119	2589	128.7	0.285	0.008
Black Iron Pipe ½" OD	0.116	2575	122.7	0.284	0.12
Aluminum Tubing ½" OD	0.21	1166	167.3	0.098	0.035
Copper Tubing ½" OD	0.092	1981	88.05	0.323	0.04

For an equivalent 100 mil diameter hole, we can derive theoretical values for heat capacity based on the aforementioned equation.

Figure 2 is a plot of the respective values for each material. It is clear from

Figure 2 that the amount of energy to create a 100 mil diameter hole is much larger for black iron pipe then for any of the other three specimens. Thus we can now see why the thickness of the pipe plays such a critical role. In fact for this particular case, the amount of energy for a conventional ½" black pipe will require ~15 times the energy that would be required to similarly melt CSST, ~10 times the energy for aluminum, and ~5 times the energy for copper.

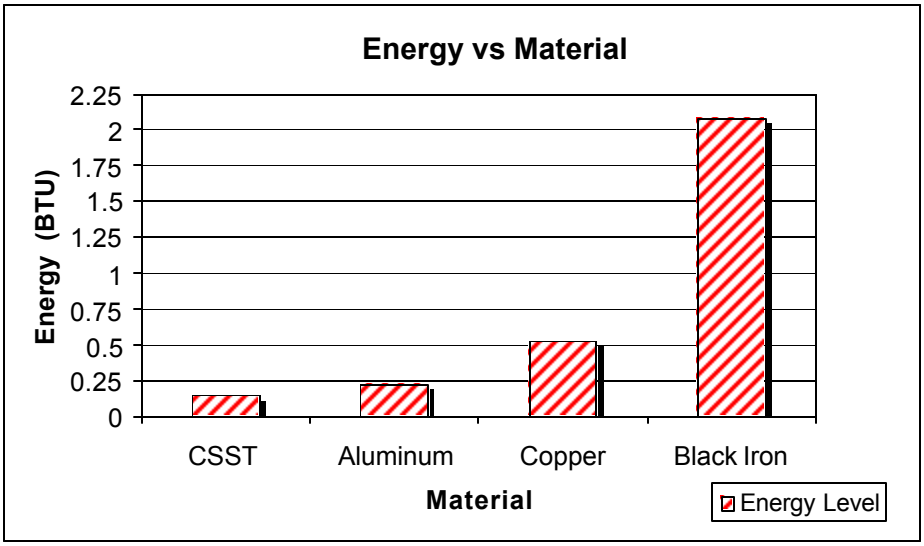

Figure 2: Comparison of heat capacity for 100 mil diameter hole in CSST, Aluminum Copper & Black Iron

LIGHTNING CHARACTERISTICS

How 'strong' is lightning? The data from Uman indicates that lightning strikes vary in current (amperes) from 10,000 to 20,000 peak (typical) to 200,000 amperes peak (maximum)[9]. Uman also lists the 'bottom' end of lightning strokes as having peak currents of 1,000 to 5,000 amperes[10]. Mechanical damage caused by heating is a function of current squared multiplied by time. Thus, the current is the dominant factor in creating the melting of the gas tubing.

FIRE INVESTIGATION

As of October 2004, we have encountered 4 fires in which we believe that lightning damaged CSST. We describe two of these fires here.

Fire 1

The fire occurred in the wood framed chimney space that had a metal chimney insert. CSST ran through the chimney space to feed the gas igniter. Four perforations were found in the CSST, ranging in size from a pinhole to a hole about 125 mils along its major axis. A STRIKE FAX lightning report showed that 4 hits within 0.1 mile of the house were recorded[11]. Figure 3 shows 2 adjacent holes that were created in the CSST.

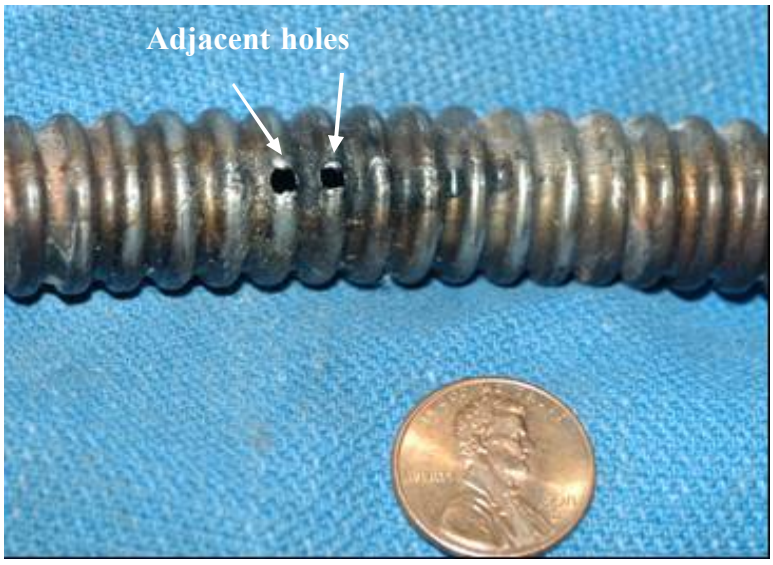

Figure 3: Adjacent perforated holes in CSST from Fire 1

Fire 2

The fire occurred in an expensive house (construction not finished) with a value in excess of 6 figures. The house was a 2 story house, and plumbed with approximately 95% black pipe. Two runs of CSST, each serving a fireplace, comprised the CSST piping in the house. A perforation with its major axis measuring approximately 200 mils was found in one run of the CSST (Figure 4). An interview with a neighbor confirmed that the audible and visual components of the strike were sensed simultaneously. A positive lightning report was obtained, showing 11 strikes within 0.5 mile. Regrettably, the house was razed before the investigation was complete. Figure 5 shows the failed CSST run to the fireplace.

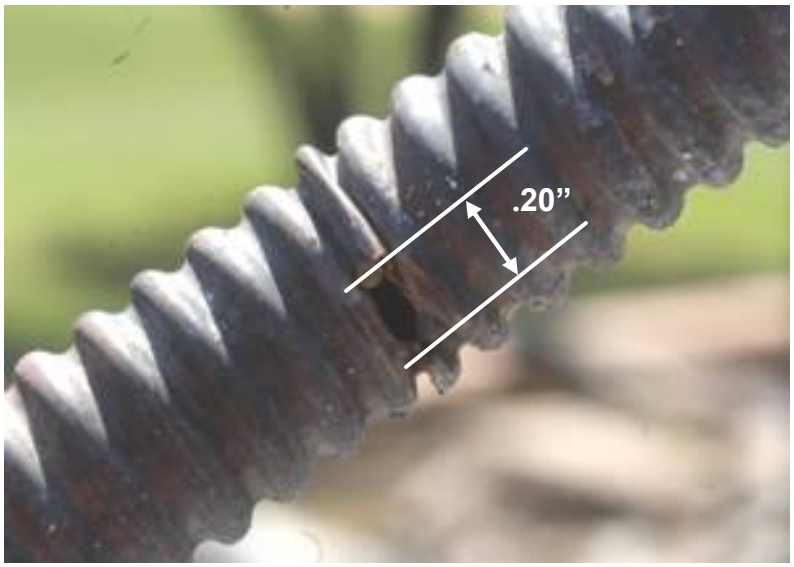

Figure 4: Perforated CSST pipe from Fire 2

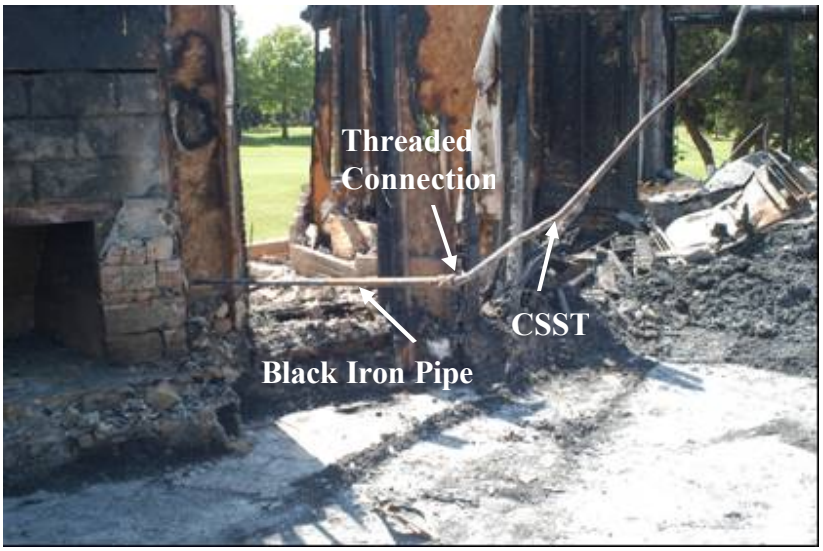

Figure 5: CSST tied to Black Iron pipe from fireplace

DISCUSSION

It would be easy to list our findings as just ‘peculiarities’ and ‘vagaries of Mother Nature.’ Indeed, one of the CSST designers has stated that the phenomenon seems to be isolated to Frisco, Texas[12]. However, a recent article in the *Journal of Light Construction* outlines similar findings of an engineering firm in the Midwestern US[13]. In a recent presentation the authors gave to a fire investigators group, we found other fire investigators who have had similar fires in their jurisdictions.

The 'Frisco' experience is noteworthy, and was in fact the impetus for our research. In short, the Frisco (Texas) Fire Department noted a relationship between lightning and CSST fires. They thereafter sought to ban CSST in. A report generated by the City of Frisco states that the continued use of CSST would not be prudent[14]. In a newspaper article in the *Dallas Morning News,* a fair reading would show that the resistance to the ban was brought about for reasons of economy[15]. We would, however, urge the reader to obtain this article and draw his or her own conclusions.

As part of our research, we interviewed the Fire Department officials in Arlington, Texas. At the time of our research, the FD in Arlington was aware of 4 fires in their jurisdiction where lightning caused CSST failures[16]. We also reviewed a report issued by Donan Engineering, where again multiple fires were described that involved lightning and CSST. These extent of the fires reviewed were located in the Midwestern United States[17].

One of the underlying issues with CSST is that it is part of the grounding system. Purists will argue that that gas piping is not to be used as a ground, and they are correct[18]. In reality, however, the gas piping system is *per se* part of the grounding system, and this is recognized by the *National Electric Code* (NEC)[19]. Per the *Fuel Gas Code*, metallic gas piping is to be bonded to ground[20].

For reasons of electric shock prevention (and also elimination of sparks associated with static electricity), it is desirable to have all exposed metal within a structure bonded so that there are no differences of potential. Here, however, lies one area where applying DC circuit theory (or even 60 Hertz steady state phasor theory) has limitations. Lightning energy is known to have fast wavefronts. Testing of devices for transient responses has typically involved an 8/20 uSec pulse, as defined by the IEEE[21]. Another variation is the 10/350 uS pulse, as recommended by the IEC[22]. While the reaction of large wires and irregular surfaces is predictable at 60 Hertz, the fast wave fronts associated with lightning may cause substantial problems with CSST, given its corrugated surface. Moreover, new house construction we have observed has shown very tight bends and routing of CSST immediately adjacent to large grounded surfaces. Testing of CSST under actual installed conditions using transient waveforms may well show further limitations that conventional bonding and grounding cannot accommodate.

CURRENT TRENDS

One manufacturer (Omegaflex) has recognized the problems that lightning poses for CSST. In response, Omegaflex has developed a jacketing material (the yellow polymer coating) that contains conductive materials; the role of the conductor is to dissipate the charge over larger areas of metal, thereby reducing current density and increasing chances for survival. Witnessed tests of the new material were described in the July 2004 *Journal of Light Construction*[23]. The reports indicate a much greater tolerance for lightning.

Correspondence received from Foster-Miller indicates that Franklin lightning rod systems will protect CSST from lightning insult[24]. However, we have not seen CSST-equipped houses being outfitted with lightning rods. The same correspondence also shows that the CSST industry is becoming aware of the problem, and will propose fixes to the other Codes (ie , NEC or Fuel Gas Code); no mention was made of fixes to the standard LC1. A further item that should be mentioned is that Foster-Miller believes that the problem does not exist in Florida, even though Florida is prone to substantial lightning activity; Foster-Miller attributes this difference to greater adherence to lightning-related Code provisions (bonding, grounding)[25].

INVESTIGATING CSST FIRES

Investigation of a fire caused by CSST and lightning is a straight forward process. One of the characteristics of CSST that makes this a simple investigation is the high melting point. Stainless steel is not prone to melt during a fire. If a hole is found in CSST, there is a good chance that the hole is from electrical current. One would need to reasonably eliminate other sources of the leak, to include eutectic melting (alloying) and mechanical damage. Microscopic work would be necessary to insure that the orifice was created by an arcing condition. As with copper wire, one is looking for sharp delineations between fused and non-fused areas. If there appear to be other metals present at the arc site, one should conduct EDX (Energy Dispersive XRay) to see if the metal being examined is stainless, or if it has other metals present (such as Cu, Zn, Al, Sn). If copper is present, one might reasonably attribute the problem to an ongoing fire attacking both the CSST and nearby NM electrical wiring – when the NM faulted to the CSST, a perforation was created. Figure 6 shows a photo taken under a scanning electron microscope (SEM) of a section of CSST that failed when touched by an energized 120 VAC copper wire.

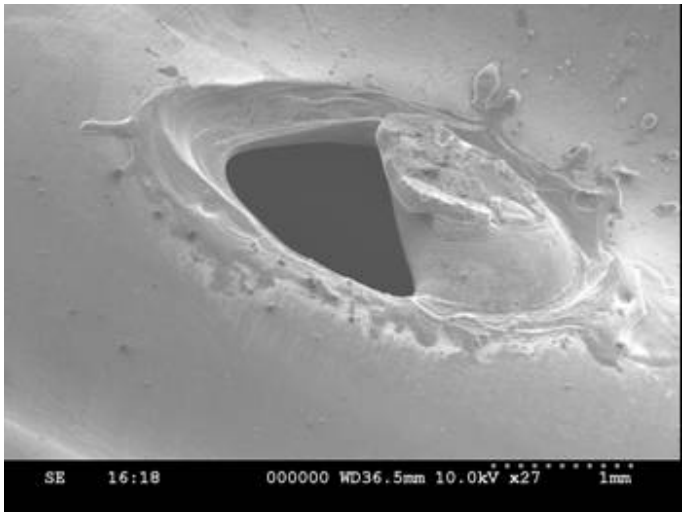

Figure 6: Hole caused by energized 120 VAC copper wire

To find holes, we recommend an instrumented leak test at ~ 7" WC air. One end of the CSST should be plugged, and each hole sequentially plugged (modeling clay seems to work the best) until the CSST no longer leaks. One of the holes we found in CSST was in an area of tubing where the polymer coating had no pyrolysis (See Figure 7). Also, Figure 8 is a microscopic view of this small leak. As in any fire investigation, the leaks and subsequent flame development must support the area of origin, or the leaks would appear to be of little consequence.

Figure 7: Photo of perforated CSST without pyrolysis

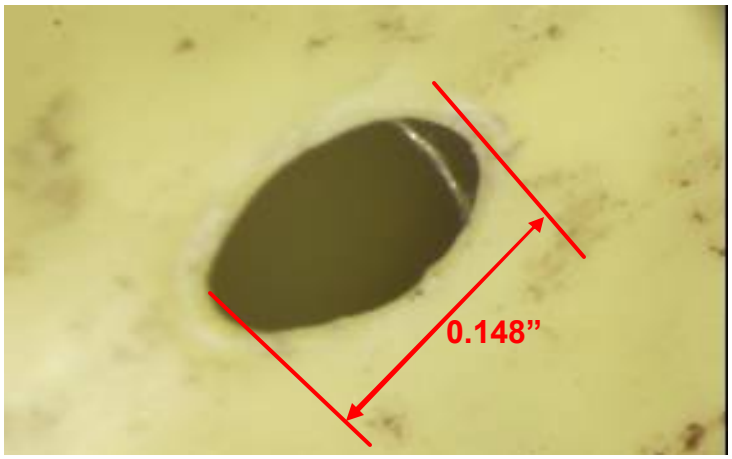

Figure 8: Microscopic View of Perforated CSST

The Frisco Fire Department Report lists escaping gas from the end connectors during lightning events as also being possible sources of ignition[26]. In a previous article written by one of the authors (MEG), this very phenomenon was described on appliance connectors[27]. The fact that a gas line fails at a connection is no surprise, in that gas lines are chosen for mechanical integrity at their junctions, and not necessarily electrical conductivity. Figure 9 shows the end of a failed appliance connector that has arced and caused a fire due to electrical current flow. We might expect to see similar manifestations with CSST at its connectors.

Figure 9: Bottom and side respective views of failed gas line from appliance connectors

In all of our investigations, we have obtained positive lightning reports via STRIKE FAX. The City of Frisco, in their investigation, also made use of STRIKE FAX reports. We must state, however, that in our opinion, the perforated gas line can normally stand on its own in terms of evidentiary value; we know of no other phenomenon that would create a clean arced hole other than lightning. If a copper wire arced to the stainless steel tubing, there should be copper remnants found. Likewise, the melting point of SS will not be reached in most fires. While the lightning reports are useful, we would add that they might add 'too much' information, if that is even possible. The reports list strike magnitude, polarity, distance, and time. If there are multiple strikes, there is a question of which strike is causative. Likewise, is it possible that one strike induced multiple perforations? We are not certain that these additional questions can be answered accurately, nor do we know to what extent these answers may be helpful. In the end, the CSST failed from lightning, or it did not – we have not been concerned as to which of multiple strikes brought on the failure.

In one of our fires, a field examination revealed the hole in the CSST. The STRIKE FAX sent thereafter to the O&C investigator was negative. And yet, a neighbor was a witness to the lightning. The request for a lightning report was re-submitted, and this time the report received was positive for lightning events at the location. In this fire, the physical evidence was very clear and helped to serve as the basis for a requesting a new lightning report.

We have not spoken of spoliation, but it is of course advisable that potential adverse parties be given notice of inspections if litigation is anticipated.

THE ULTIMATE QUESTION:

The ultimate question is whether or not CSST is safe as currently installed. We would offer initially that there is one similar product that reminds us of CSST. Aluminum wiring was approved by the NEC and by a recognized testing group – UL. Aluminum wiring was installed for reasons of economy, in that it was less expensive than copper. Aluminum wiring was also never adequately tested before being placed on the market. We later learned about creep, dissimilar thermal coefficients of expansion, and the insulating properties of oxidized aluminum. When adequate testing was conducted, it was realized that aluminum had numerous problems not posed by copper. Wiring on the inside of houses and business is now all copper, which does not pose the risks associated with aluminum,

In the case of CSST, we know of one manufacturer diligently trying to alter the product so as to prevent losses. We are also aware of the industry proposing changes to codes so as to make CSST less of a threat during lightning. These alterations, combined with mounting fire losses involving CSST and lightning, would suggest that it has deficiencies. The underlying issue, however, is whether or CSST is as safe as conventional black pipe. In this regard, reported fire losses indicate that it is not as safe as black pipe in

regards to the issue of lightning. While we cannot state that black pipe will never fail from lightning, we have yet to see such a fire.

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