INVESTIGATING THE CAUSAL LINK BETWEEN LIGHTNING STRIKES, CSST AND FIRE

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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 claimed include a lack of connections and a lack of pipe threading - in essence, it is a material that results in substantial cost savings (relative to black pipe). CSST is recognized by ANSI /IAS LC-1 –1997 [1] CSST consists of a stainless steel corrugated tubing that is sheathed by a polymer conformal coating. There are several manufacturers of CSST, and each has their own particular brass fittings / ends that serve as couplings. CSST can be thought of as a form of a very lengthy appliance connector, also taking the place of the rigid piping in a structure.

Over the last several years, fires have occurred that have been attributed to the failure of CSST when insulted by lightning. We outline here the development of CSST, as well as the theoretical aspects of CSST susceptibility. We also show important factors in conducting a CSST investigation.

CSST Development

The introduction of CSST into the United States was brought about by a firm called Foster-Miller. [2] 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. [3] However, we caution the reader to review the literature and draw his / her own conclusions. 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. [4]

Each manufacturer requires a potential installer to take a several hour installation course. The installation courses are required as part of ANSI LC1, and are an attempt to insure only qualified installers make use of CSST. This arrangement should prevent CSST from being available at home improvement stores. [5]

CSST was first recognized by the NFPA in the *Fuel Gas Code* NFPA 54 in 1988. [5] The IAPMO finally approved CSST in 2003. [7] It is interesting to note that in 2000, the IAPMO rejected CSST for reasons of safety. The Foster-Miller documentation submitted in 2000 to the IAPMO states that there have been 50 million feet of CSST installed without one reported failure. [8] Now that there have been numerous reported failures (outlined later), IAPMO action on CSST will be of interest. We do note that the IAPMO submitted a request to the NFPA 54 Panel, requesting uniformity in installation instructions due to the reported number of fires occurring. [9] For the purpose of this article, we have analyzed and evaluated all of the CSST brands except for Omegaflex's new product which is marketed as Counterstrike. All of the other CSST brands have the same essential design and physical properties. According to the Omegaflex's marketing material, Counterstrike has a conductive polymer coating to prevent failures due to lightning strikes. Since we have not personally analyzed or evaluated the physical properties and effectiveness of Counterstrike, this paper addresses the failure mechanism of all other brands of CSST except for Omegaflex's Counterstrike product.

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 (assuming NG and not propane). 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 from the manifold; 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 the residence, and 3 separate runs (1 for each appliance).

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 yellow polymer jacket. Test pressures are higher for CSST than black pipe, but we find this somewhat of a 'red herring' when compared to conventional plumbing; we know of no need to increase the Factor of Safety (FS) for black pipe – pipe installations tested in the field at 20 psi and then used for carrying 7" WC has provided satisfactory service 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.

Failure Aspects

CSST is extremely thin, with walls being about 10 mils or less in thickness. This lack of mass, necessitated by the desire for easy routing of the tubing, has resulted in a material that is easily perforated by electricity. Once the tubing has been perforated, gas will escape and likely be ignited by the metallic by products of the arcing process, by autoignition, or by adjacent open flames.

Analyzing this process requires a uniform, mathematical formula based upon recognized physical and chemical properties. The 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:

$$q = C \cdot m \cdot \Delta T_m + m \cdot H_f$$

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.

Lightning damage to black pipe is usually so small that it is only visible with microscopic analysis. Given the thickness of black iron pipe, damage from lightning is limited to a small pit which does not leak any gas and be subject to ignition. In contrast, when electricity from lightning contacts the CSST, the product fails due to its design and physical properties. Table 1 lists the relevant properties for specimens of black iron, CSST, aluminum, and copper tubing.

Table 1

Material	C (BTU/lb F)	T_m (°F)	H_f BTU/lb	Density (lb/in³)	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 calculate the values for heat capacity based on the aforementioned equation. Figure 2 is a plot of the respective values for each material. The amount of energy to create a 100-mil diameter hole is much greater for black iron pipe then for any of the other three specimens. See Figure 2. Thus, the thickness of the black pipe is critical to prevent fires post lightning strike. In fact for this particular case, the amount of energy for a conventional ½" black pipe will require ~15 times which would be required to similarly melt CSST.

In addition to the 'thin wall' heat transfer / fusion aspects of CSST, CSST's design allows it to be easily bent and shaped during installation. While flexibility makes installation easier, it also creates risk in terms of electric field enhancement. A corona is created when an electrical field is enhanced by virtue of the geometry of the electrodes, such that there is ionization of the air and resultant breakdown. In regards to CSST, a 'sharp' bend of CSST can enhance the electrical field during a lightning strike such that the CSST becomes one of the electrodes. The lightning then causes the CSST to fail. Mathematically, the reader can refer to Poisson's Equation, as well as Gauss's Law (a special form of one of Maxwell's equations) to show relationship between charge density, gradient, and electrostatic potential. These equations and the manifestation of lightning upon CSST systems are exemplary of the corona phenomenon.

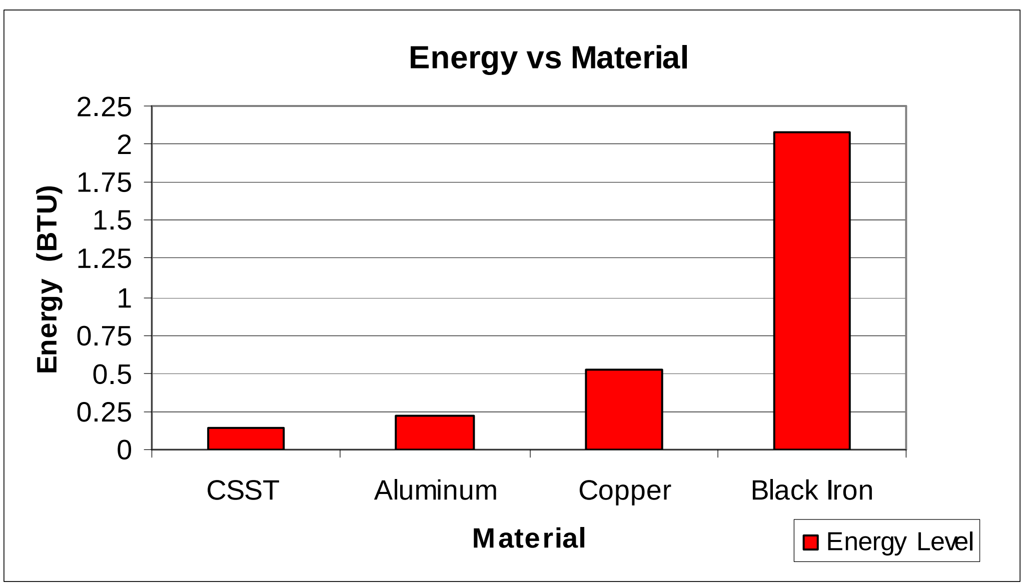

Figure 2 Comparison of heat capacity for 100 mil diameter hole in CSST, Aluminum & Black Iron

Fire Occurrences

In the United States, fires attributable to CSST are increasing. For example, the following are just some examples of fires related to CSST in homes:

1.) Carmel, Indiana – reports 6 fires in 2 years [14]
2.) Donan Engineering [15]
3.) City of Frisco News Release [16]

The ‘Frisco’ experience is noteworthy, and was in fact the impetus for our own 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.

As part of our research, we interviewed the Fire Department officials in Arlington, Texas. At the time we started our research, the FD in Arlington was aware of 4 fires in its own jurisdiction caused by CSST failing after lightning. [18]

<u>Fire Investigation</u>

As of May 2005, we have encountered 5 fires in which we believe that lightning and CSST brought about catastrophic results. We describe 2 of these fires herein.

Edmond, Oklahoma

The fire occurred in a two story house under construction, plumbed with approximately 95% black pipe with a value in excess of $1,000,000. Two runs of CSST, each serving a metal chimney, comprised the CSST piping in the house. A perforation with its major axis measuring approximately 200 mils was found in the CSST; this is shown in Figure 3. A positive lightning report was obtained, showing 11 strikes within 0.5 mile. Figure 4 shows the failed CSST run to the fireplace.

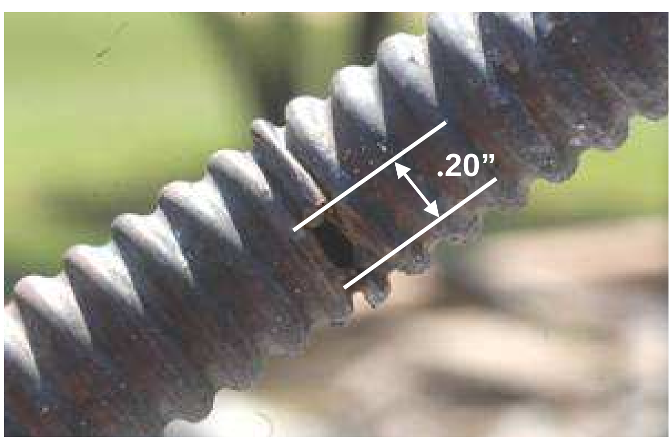

Figure 3: Perforated CSST pipe from fire in Edmond, OK

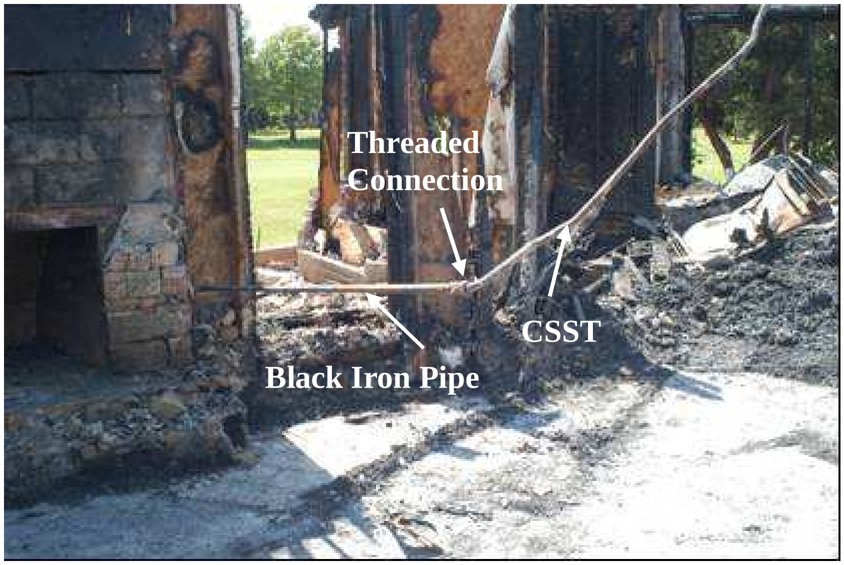

Figure 4: CSST tied to Black Iron pipe from fireplace

Cedar Hill, Texas

The fire occurred within the attic space of a home, which included several runs of CSST. The CSST runs went to a fireplace, furnace, range, and water heater. During a lightning storm, the CSST run serving the fireplace leaked and the resultant fire then destroyed a section of the attic. A perforation measuring 95 mils along its major diameter was found in the pipe. A lightning report showed that there were approximately 5 strikes within 0.3 mile of the house. The fire was contained within the attic, but subjected the house to extensive smoke damage. Figure 5 shows the burned section of the attic as a result of the fire that occurred during the lightning storm. Figure 6 shows a view of the arc site of this same failed CSST when viewed under a Scanning Electron Microscope (SEM).

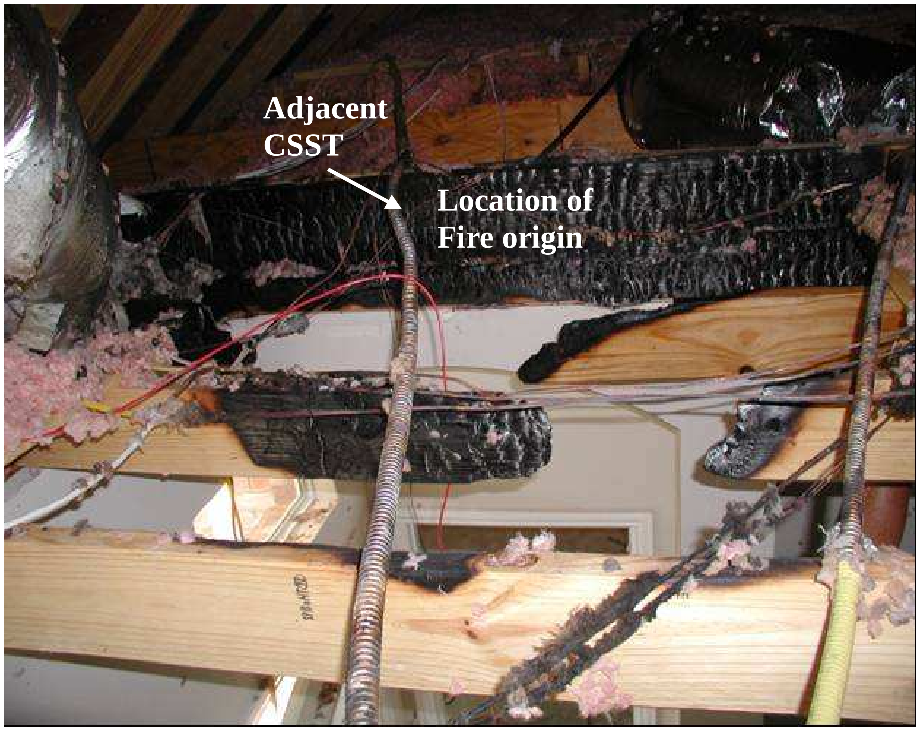

Figure 5: Attic fire during lightning storm Cedar Hill, TX.

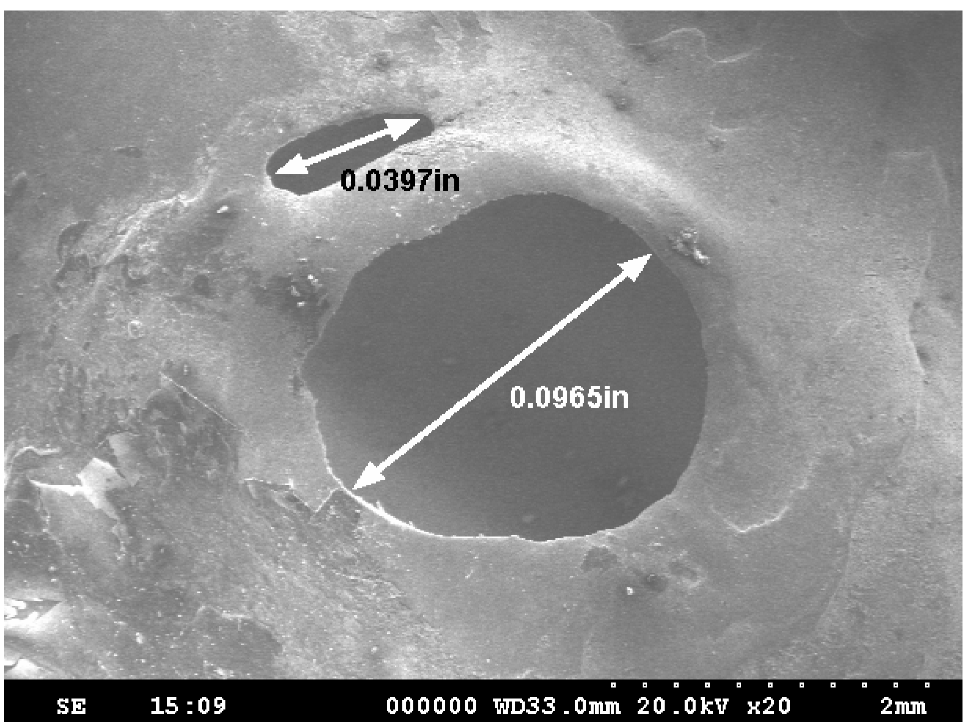

Figure 6: Arc holes in CSST @ 20X induced by lightning

Investigating CSST Fires After a Lightning Strike

Investigation of a fire caused by CSST and lightning requires a uniform approach. The physical properties of CSST gives the product a high melting point. Stainless steel is not prone to melt during a fire. If a hole is found in CSST after a fire, the source / cause of the hole needs to be determined. The ANSI LC1 specifications for CSST (in terms of material and thickness) are so uniform that there should be no substantive differences among the CSST brands as to the way they are damaged by lightning. If an arced hole is found in a length of CSST after a lightning storm, and the arcing was not caused by energized wire contact, then the only other cause of failure is lightning insult. Thus, all other causes of the fire can be reasonably eliminated other than the lightning strike. There is no other condition that can mimic this same physical evidence.

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 (with modeling clay) until the CSST no longer leaks. One of the holes we found in a CSST investigation was in an area of tubing where the polymer coating had no fire damage, as shown in Figure 7. In Figure 8 we see a microscopic view of this small leak (three other holes on this same length of CSST occurred in areas where heavy pyrolysis to the coating had occurred). As in any fire investigation, the leaks and subsequent fire 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

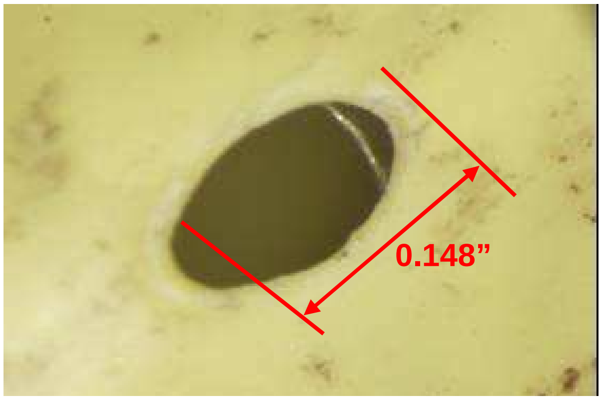

Figure 8: Microscopic View of Perforated CSST

The Frisco Fire Department Report lists escaping gas from the end connectors during lightning events as also being possible sources of ignition. In a previous article written by one of the authors (MEG), this very phenomenon was described on appliance connectors. [19] 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.

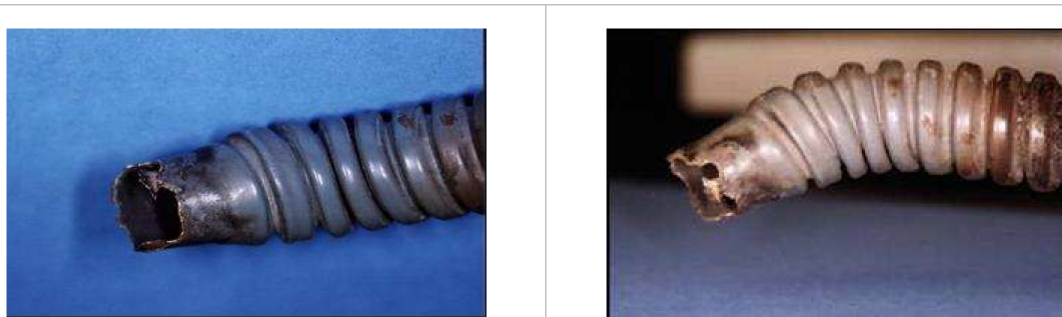

Figure 9: Bottom and side respective views of failed gas line from appliance connectors (Not CSST)

Figure 10: Adjacent perforations in CSST

Figure 10 shows a length of CSST in which there were two perforations in adjacent furrows of the tubing. We have seen as many as 4 holes in one CSST length after a fire.

The common factors in all of these fires are the presence of CSST in the homes and positive lightning reports via STRIKE FAX. The City of Frisco, in their investigation, also made use of STRIKE FAX reports. While the perforated gas line can normally stand on its own in terms of evidentiary value, the physical evidence leads to only one conclusive answer because lightning is the only phenomenon that would create a clean arced hole.

We are also of the opinion that bending radii of any damaged CSST piece should be determined, if the damage occurs at a bend. One manufacturer is now recommending that CSST be installed with certain minimum size bends (8") in areas known as "High Lightning Strike Regions. [20]

The investigator should determine how the CSST is bonded to the grounding system. In the previously referenced *NFPA 54 Report on Comments*, the IAPMO makes the following recommendation and comment to the NFPA 54 committee:

Create clear minimum bonding and grounding requirements for metallic fuel gas piping. Bonding and grounding guidelines for metallic fuel gas piping differ between NFPA 54 and ANSI LC 1/CSA 6.26. NFPA currently contains no specific requirements for bonding or grounding of CSST. LC 1 states that the manufacturer shall provide the method in their instructions, however, there is no consistency between manufacturers. [21]

Remediation

During our investigations, we have been asked by homeowners as to how they can rectify the problem. One homeowner wants to go to an all electric home, while others want the CSST replaced by black pipe. These tasks are not too difficult for the fire damaged house being rebuilt.

For a house that is not damaged, however, the owners will have to incur substantial expenses by undertaking one of these 3 remediations: 1) convert the structure to electricity only and remove all gas delivery; 2) retain gas but remove all CSST from the structure and install black iron pipe, or 3) prevent lightning from contacting the CSST which would prevent perforation and ensuing fire – i.e., install a NFPA 780 type lightning arrestor system. Without paying for the costs associated with one of these 3 solutions, homes or structures containing the CSST are subject to fire due to the uniform failure when electrical current caused by lightning contacts the CSST.

Summation

By using a uniform methodology to analyze the physical properties of CSST, and also by knowing the electrical properties of lightning, we are able to conclude that CSST fails when the CSST is contacted by electrical current associated with lightning. Due to its uniform design (in accordance with ANSI LC-1), all CSST fails in the same manner when insulted by lightning: electricity contacts the CSST, the CSST acts as a conduit for the electrical current, the electricity perforates the pipe and permits gas to escape. During this process, there is ignition of the escaping gas. This problem uniformly affects all CSST brands, in that the products have the same inherent design, thickness (or lack thereof) and physical properties. In contrast, the thickness and physical composition of black iron pipe prevent perforation when the black iron pipe is contacted by electrical current during a lightning strike.

References:

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