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Electrical Damages—Cause or Consequence?

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ABSTRACT: This article shows the difficulty in recognizing electrical damages that are causes from those that are consequences of a fire. Different types of mechanical damages to electrical cables illustrate the difficulty in starting an electrical fire. Damages to electrical cables in a fire environment are also illustrated. Some field cases are discussed. Many normal consequences of fires are often taken as the cause.

KEYWORDS: forensic science, fires, electricity

A fire is a complex chemical and physical phenomenon [*1-3*]. The damages from a fire can vary from superficial charring to complete destruction. The progress of a fire is greatly affected by many variables over which the fire investigator has no control. The extent and type of damages are affected by the nature and disposition of the building materials, the ventilation, the fire fighting techniques, and so on. The complexity of a fire renders the fire investigator's task very difficult in most instances. In that respect, electricity presents a particular challenge. It is often difficult or impossible to recognize the damages to electrical wiring that are associated with the causes from those that are consequences [*4-7, 9*].

This problem of electrical damages as the cause or consequence is present in most fires. To find the cause, most of the time, one must first recognize the point of origin. The point of origin is in fact an area of origin in many cases. Often, the point of origin cannot be determined exactly. Sometimes, a full room or even a large part of a building has to be accepted as the point of origin. Obviously the preciseness of the point of origin depends to a large extent on such factors as: the extent of damages, the nature of the combustible materials, and the fire fighter's actions.

Whatever the point of origin, most likely there will be some electrical installations around that point. In a single residence, there are over 300 m of cables, 30 m of extension cords, some 70 electrical outlets, and many applicances and motors. Finding 50 electrical motors in a single residence is not unusual.

In this article, the danger of electrical fires from mechanical damages will be examined first; then damages to cables in fire environments will be reported. Most of the tests were conducted in a laboratory under controlled conditions representative of reality.

Mechanical Damages

When a cable is subjected to mechanical damages such as squeezing under a staple or driving a nail through it, the conductors are eventually short-circuited. The short circuit

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could also occur between one of the live conductors and ground. Two dangers of ignition need to be considered: the sparking and arcing at the point of short circuit and the heating of the cable that feeds the load up to the point of short circuit.

A short circuit results in a high current which opens the fuse or breaker quickly. No appreciable heating of the conductors could take place in any normal installation. It is very seldom that dangerous temperatures could be reached following a short circuit. This is possible only under the most exceptional circumstances unlikely to be met in practice. Even a 100-A fuse protecting a 14/2 copper cable will not cause dangerous heating of the conductors under many if not most short circuit conditions. A short circuit is not an overload. In fact, many examples could be given where a No. 18 conductor will not heat dangerously following a short circuit when the protection is at the 100-A level. In some cases, the increase in temperature is barely perceptible.

At the point of short circuit, some sparks are produced. The amount of sparkings increases with the ampacity of the fuse or breaker. It is usually more important with breakers than with fuses for a given ampacity. Some makes of breakers are slower than others and produce more sparkings. The higher the available short circuit current, the more important the amount of sparkings. If a short circuit occurs close to a high power source, more sparkings result than if the short circuit occurs at some distance from the source. The amount of sparkings further depends on many other variables difficult to control such as surface oxidation, the manner in which the conductors are brought together, the type of insulation, and so on. Furthermore, the results vary from test to test under apparently similar conditions. Therefore, the amount of sparkings and the danger of ignition is difficult to predict; it involves probabilities. Only general remarks can be made even if the circuit is well-known. The heating of the cable however can be predicted accurately if the electrical system is known.

This author has made thousands of short circuits under different conditions and in the presence of different building materials. Only the main points will be reported. Figure 1 shows nonmetallic sheathed (NMD) cables (braided and plastic types) that were hammered until a short circuit resulted. The circuit was protected by a slow-acting 15-A circuit breaker. The short circuit current was 1000 A for a period of 4 cycles or 0.07 s. The insulation is barely charred on a few spots. Figure 2 shows many 12.7-mm (1/2-in.) electrical metallic tubings (EMT). They were hammered or squeezed in a vice until a short circuit occurred. It will be noted that some conduits have no apparent electrical damage on the exterior. These correspond to circuits protected by 15-A fuses or circuit breakers. The small pin holes were ob-

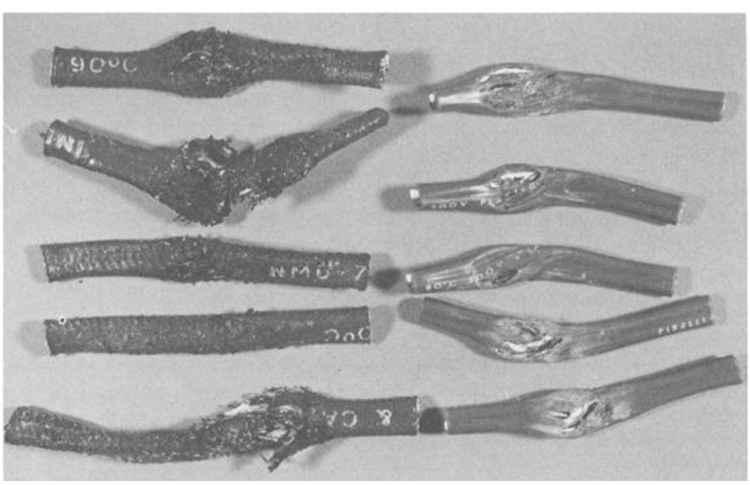

FIG. 1—*Hammering of 14/2 copper cables.*

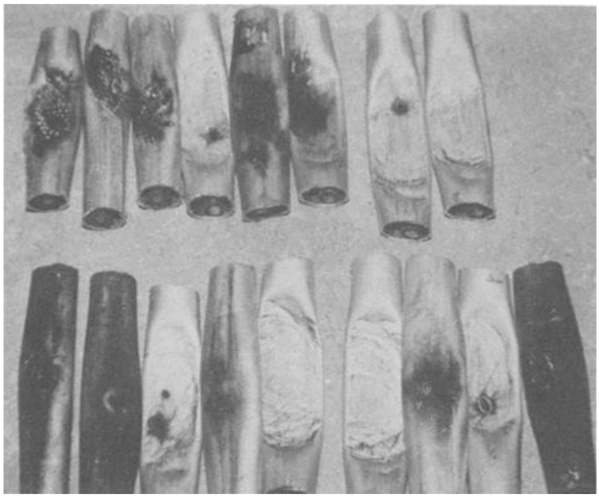

FIG. 2—*Damages to EMT systems.*

tained with 15- and 30-A circuit breakers. The heavier damages were obtained with breakers ranging from 40 to 100 A. Figure 3 shows a 12/2 armored cable that was hammered while the protection was a 15-A circuit breaker. Figure 4 was obtained under the same conditions as that of Fig. 3 except that the breaker had a 30-A rating. The source had a short circuit capacity of 1500 A.

The amount of mechanical abuses must be very high to obtain an electrical breakdown. Often the breaker opened only after many partial short circuits particularly for the higher ampacity breakers. The flexible armor and EMT have a spring-back effect. Following many hammer blows, there will be some sparkings but the breaker may stay on. It opens sometimes only after many blows. That type of intermittent short circuit is particularly destructive since following the separation of the conductors, arcing is initiated. Sustained arcing has never been met however. At the most, it lasted for a few seconds. Even for damages such as that in Fig. 4, it is very seldom that the conductors were severed. In most cases, there was just

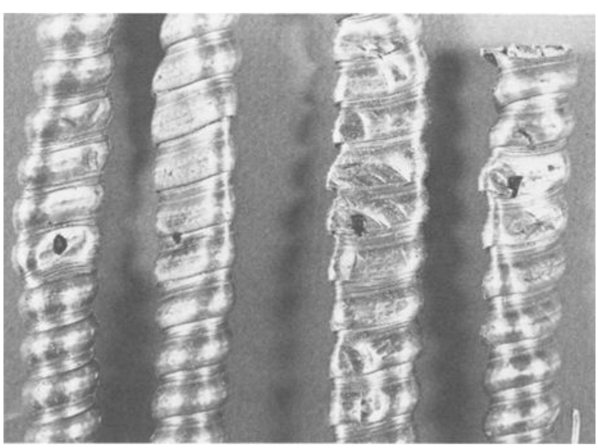

FIG. 3—*Damages to a 12/2 BX cable protected by a 15-A, FPE Stab-Lok® breaker.*

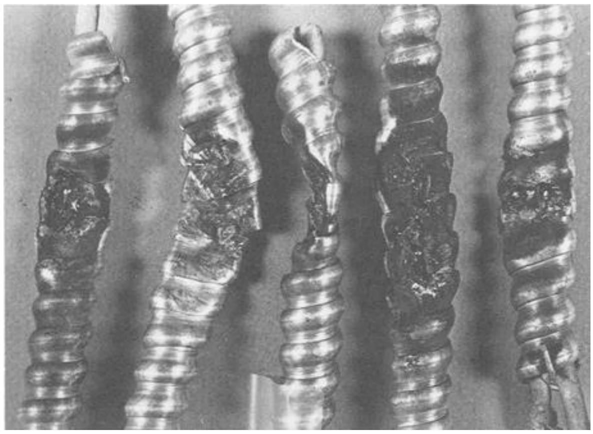

FIG. 4—*Damages to a 12/2 BX cable protected by a 30-A, FPE Stab-Lok breaker.*

superficial melting. The insulation was charred superficially in localized areas. No ignition of the insulation took place.

None of these tests could have ignited a solid piece of wood under normal circumstances. Even wood shavings and paper are not usually ignited with protection at the 15-A level. With 30 A, the danger is much higher although ignition does not take place on every test. Obviously, that danger depends a great deal on the type of paper or wood shavings. Hygienic tissues for example are easy to ignite. Very fine and dry wood shavings are likewise easy to ignite. The danger of ignition from electricity is occasionally tested with surgical cotton. This material is used because of its ease of ignition. The fact that it is ignited should not be used to conclude that electricity is dangerous. On the contrary, this test just proves that surgical cotton is extremely easy to ignite. It can be ignited with small sparks from a grinding wheel. If a flaming match is brought in close proximity, this material will flash over quickly.

The sparks produced from such testings are small. They will not ignite sheathing fiberboards. However, for damages such as that in Fig. 4, if they happen at the junction of two panels and assuming some fibers are already loose, ignition resulted in half of the tests. It must be recognized that this is a particular situation; a match ignites the boards in about 1 s in such a case. With a 30-A slow-acting breaker, with a source having a short circuit capacity of 2000 A, in the worst cases about 0.01 cm^3 of copper was melted and the armor was pierced for a total area of 1 cm^2. This is to be compared with the arc welding process. In that case, that amount of metal is melted in a fraction of a second notwithstanding the fact that welding operations last for many minutes. Then large globules of metal are produced in an almost continuous operation. That welding process is often performed close to combustible materials. While dangerous, that process seldom results in a fire.

Bringing two bare conductors in contact to make a solid short circuit produces much less damages than that obtained through mechanical damages. Usually, there is minimal superficial melting at the point of short circuit. The damages shown in Fig. 5 were obtained by shorting a bare No. 14 copper conductor on the exterior of the armor. All other conditions were as that for Fig. 4.

Nails were also driven through different cables. The damages resulting from a nail are much smaller than that obtained through hammering for given electrical conditions. In the case of EMT, a hole was first drilled before inserting the nail. It is a relatively simple task to drive a nail through an armored cable (both aluminum and steel armors were tested). It must be noted that if a nail is driven at random through a cable, most of the time no short circuit

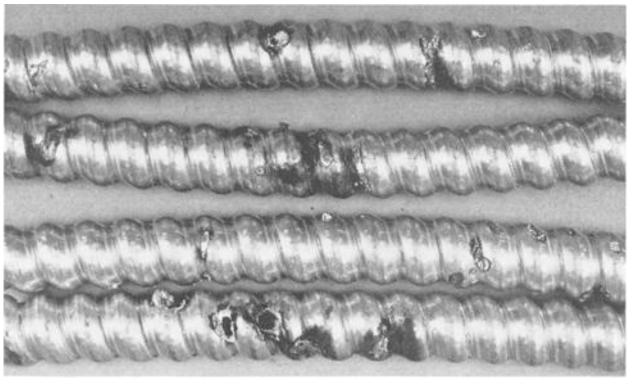

FIG. 5—*Damages from short circuits.*

will result. If a short circuit results, the melting of the nail and of the conductor is minimal. Often, it can barely be seen except under close examination.

These tests were conducted with short circuit capacity of up to 2000 A. Most short circuits in a residence will result in a current between 200 and 2000 A for a small fraction of a second. Short circuit currents somewhat above 2000 A are possible only under exceptional circumstances. This will happen only if the short circuit is very close to the main entrance switch, the house is very close to a large power transformer supplying many houses, and the house is situated in a densely populated area. For example, a short circuit on a 14/2 cable at a 3-m (10-ft) distance from the main breakers leads to a short circuit current of about 1000 to 2000 A.

It is often claimed that sharp bending of cables, minute stretching, and vibrations over a period of years will eventually lead to failure of cables and the resultant arcings and sparkings. These hypotheses are often made by fire investigators following a fire. Usually, the only evidence is that some electrical installations were around the area of origin of a fire. The amount of mechanical abuses to obtain a short circuit is very high for most types of cables. Often the original diameters of the cable systems had to be reduced to about 20% of their original thicknesses to obtain a short circuit. Figures 1 to 4 illustrate the amount of necessary damages. The nonmetallic cables of Fig. 1 were twisted before hammering so that one conductor was above the other to facilitate the short circuit.

Bare Conductors

Bare conductors, even when in close proximity, present no problem unless there is a conducting path between them. Fire investigators have sometimes claimed that this constitutes an air gap and therefore there is the danger of an arc. This is not so. The mere presence of an air gap does not induce arcing. Even 300 V will not jump an air gap that has a length equal to the diameter of a human hair. There is however the possibility of having the conductors brought into contact. This constitutes a short circuit which was discussed in the previous section.

The space between two bare conductors could however become contaminated by conducting airborne particules; then, there is the possibility of having a conducting path and an eventual arc depending on the nature of that conducting path. This possibility is slight under most circumstances as shown by the following.

Figure 6 shows plastic and braided types of nonmetallic sheathed cables. The insulation was skinned as shown so that the bare conductors were visible for a length of 2 cm. The

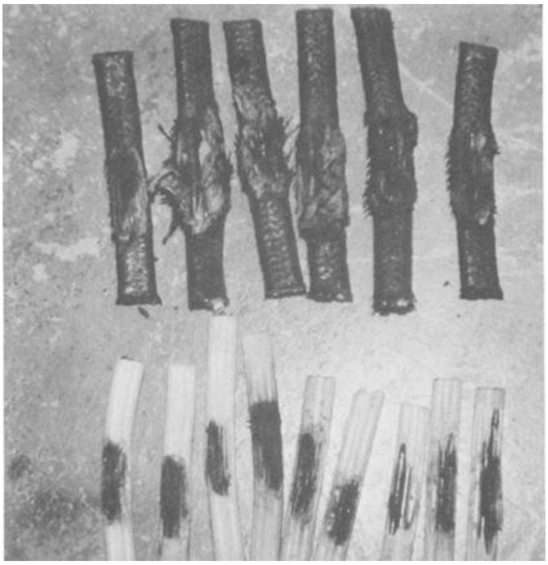

FIG. 6—*Damaged cables in presence of conducting particles.*

cables were protected by either a 15- or a 30-A breaker. Then, for days, different materials were manipulated on the bare conductors. This includes salted water, carbon granules, metal filings, and so on. Of course, insulating materials such as sawdust, plastics, and wood shavings have no effect. Salted water lead to hairline luminous conducting paths until all water was evaporated. On occasions, boiling water could be observed. Conducting (metallic dusts and filings) and semiconducting materials (carbon dusts and granules) also lead to intermittent glowing hairline paths. Occasionally, small exploding flashes could be observed. The breaker tripped many times and was put back on. No flaming insulating material could be observed after days of testings. In certain instances, the conductors were completely eroded and had to be changed. Fine wood shavings and tissue paper, however, were ignited on a few occasions.

These tests show the difficulty in starting and maintaining a stable arc under residential conditions. Not only an arc is difficult to start, but, once started, it usually operates the protective device quickly. There are however conditions under which arcing is not only possible but it is easy to obtain. Arc welding process is an example. In that case a high-current, low-voltage power source with a high internal impedance is especially designed to stabilize the arc. Furthermore the electrodes are specifically designed and covered with a flux coating. Any one doubtful of the especially designed power source and electrodes should try to weld with standard power sources and wires; he is in for a surprise. At higher voltages such as 600 V, the problem is entirely different and stable arcing does occur under certain circumstances.

Cables in a Fire

Notwithstanding this difficulty in starting and maintaining a stable arc, if one visits the remains of a fire, he finds much evidence of arcings. That arcing is evident by the melting of copper conductors in many places. Conductors are destroyed over length varying from a few millimetres to many centimetres, or even a metre in some instances. It is known that copper will not melt in most residential fires. Since aluminum melts easily, the presence of molten aluminum cannot be taken as evidence of arcing. Evidence of melted copper conductors is reasonable evidence that arcing has taken place. However, since it occurs in most fires and in many places, one cannot associate that evidence with the cause; in fact, it is a normal consequence. This point was discussed at great length in Refs *6–10*.

When a live cable is put in a fire environment, its insulation is gradually pyrolyzed and destroyed. The insulation is changed to a carbonaceous product. This acts as a semiconductor between the wires and spurious spikes of current can be observed either visually, by the sound thus produced, or with a current detector. Eventually, an arc is established. That arc is quite stable and can last for a long time without opening the fuse or circuit breaker. Centimetres or even a metre of cable can thus be destroyed by the arc. The voltage across the arc is of the order of 100 V and this voltage drop limits the arcing current to such low values that the protection takes a long time to operate or may not operate at all. This arcing process is highly destructive and is accompanied by high intensity light and much sparkings. This has been colorfully described by the fire fighters as: "The fire was running on the cables."

Figures 7 and 8 show two types of nonmetallic sheathed cables that were heated with a propane torch. The cables are 14/2 copper conductors and the circuit at 120 V was protected by a 15-A circuit breaker. Figure 9 shows typical damages sustained by 14/3 BX cables that were put in a wood fire under the same electrical conditions as above. Figure 10 shows the damages to some 12.7-mm (1/2-in.) EMT which were installed above a wood fire. The electrical installation was as above. In all cases, the inside conductors were energized while the tube served as the ground as it will be in a typical installation. Numbering the tubes 1 to 5 from left to right, the following comments can be made. Tubes 1 and 5 had No. 8 copper conductors inside the tubes. The conductors being large, they melt slowly and the arc moves slowly. Tubes 2, 3, and 4 had No. 14 copper conductors. These small conductors are easy to melt and the arc moves at a higher speed. That explains the less localized damages. By properly chosing the conductors, the breaker, and the source impedance, one can melt just as much conduit or cable as desired in a fire environment. Figure 11 shows a close-up picture of some of the No. 14 copper conductors that were recovered from the above experiments. Note the familiar beaded wire which can take almost any form. These evidences are normal

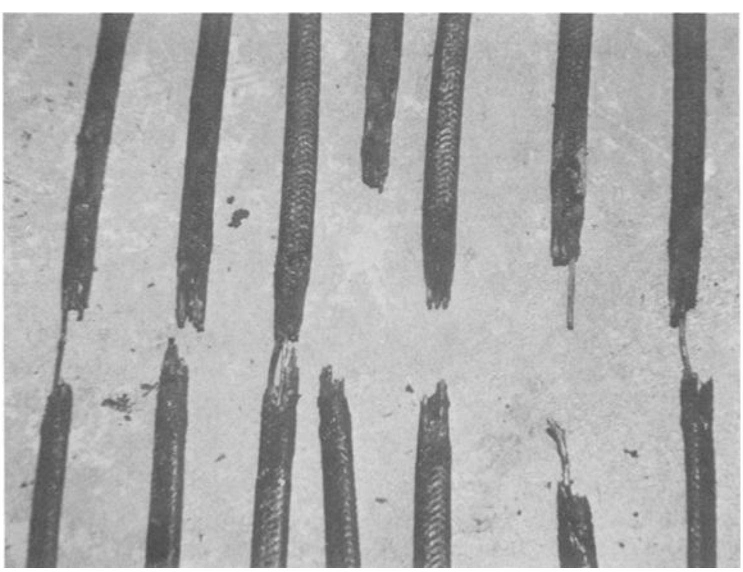

FIG. 7—*Braided nonmetallic sheathed cables heated by a propane torch.*

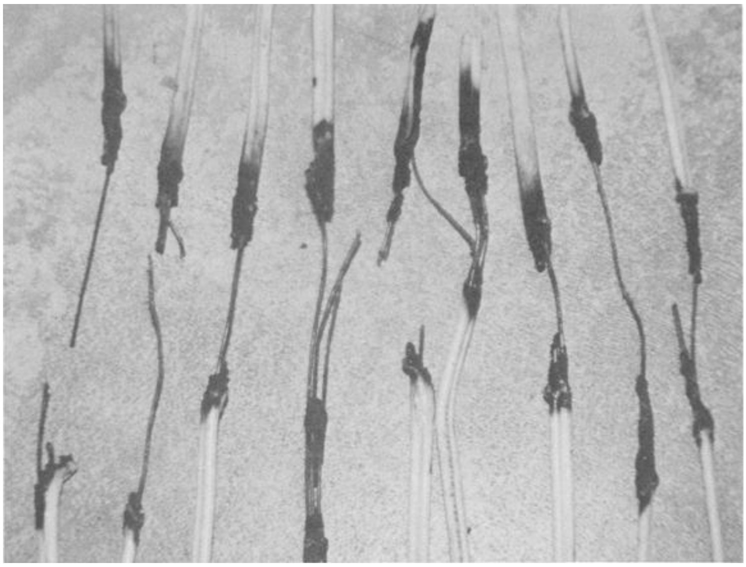

FIG. 8—*Plastic nonmetallic sheathed cables heated by a propane torch.*

consequences of a fire. It is regrettable that many authors have shown similar evidence and claimed that to be the cause [*11-13*].

Service Equipment

It would have been noted that in a fire environment, insulation is pyrolyzed and arcing eventually takes place. In fact, the heat could take any form. It could come from a very high ambiant temperature or from severe overloading. The higher the temperature, the shorter

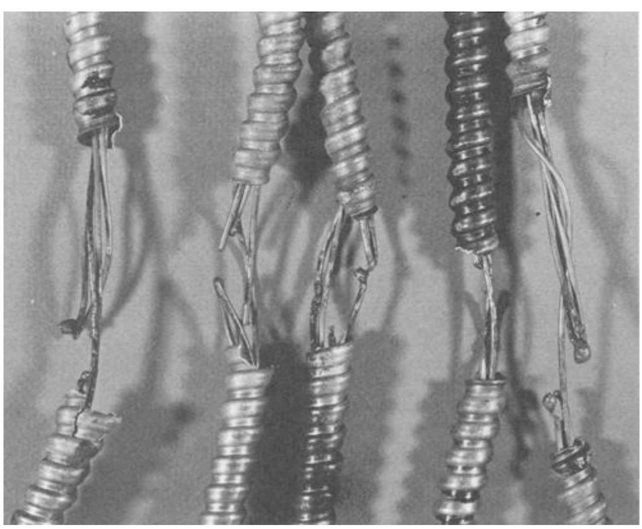

FIG. 9—*Damages to 14/3 BX cables in a wood fire.*

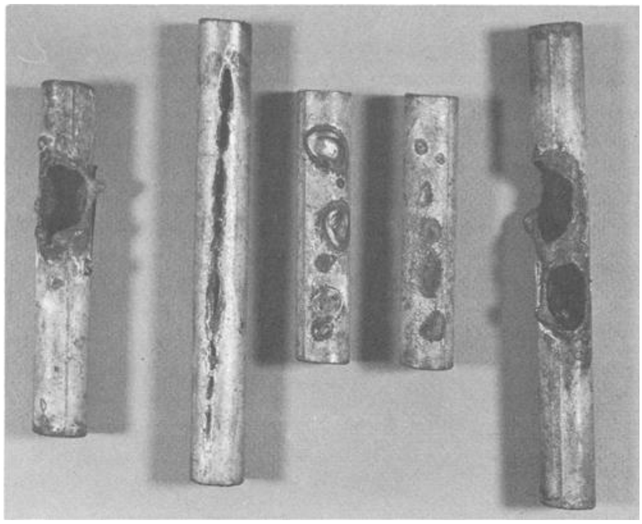

FIG. 10—*Damages to EMT in a wood fire.*

the time to arcing and the more significant the damages [8]. The temperature at which arcing takes place is difficult to specify since it depends on the operating time and the type of insulation. It would seem that induced arcing through heating occurs only at temperatures well above 100°C, often at 200 or 300°C.

In service equipments such as the main distribution panel of a residence, many conductors are grouped in close proximity. There are hundreds of electrical contacts in a small volume between the fuses, bus bars, conductors, and so on. Each one heats the next one. That equipment functions with no problem for years in most cases. Occasionally, however, they may fail. A poor contact, or other reasons, could lead to localized heating and the pyrolysis

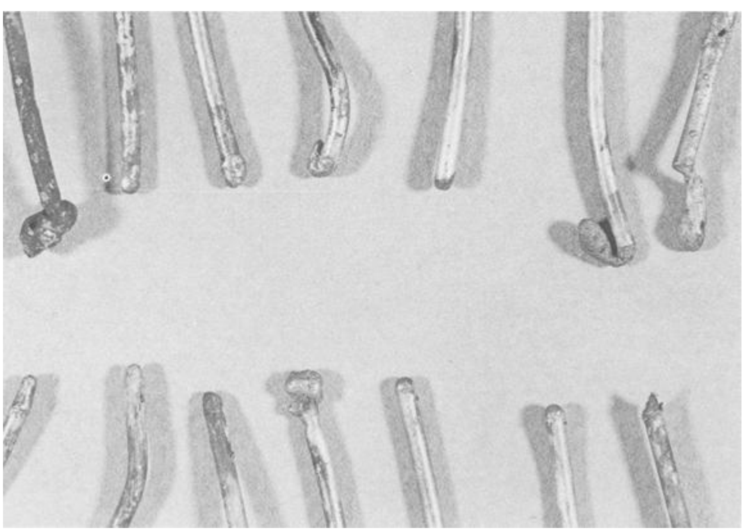

FIG. 11—*Typical beaded conductors.*

of the insulating materials. Then an arc could result. That arc is particularly damaging in that case for two reasons. Firstly, it is quite stable since it occurs through pyrolyzed insulation. Secondly, the high ampacity fuses (100 or 200 A) could lead to a long lasting and destructive arc.

This author had the opportunity to inspect such equipment which have either started a small fire or where the problem was detected before the eventual catastrophic failure. It must be realized however that if such a piece of equipment is recovered from the fire debris, usually no conclusion could be reached even if evidence of arcing is present. That arcing could just as well be a consequence of the fire. In fact, that arcing is a normal consequence of a fire although, in some cases, it could be the cause. In most cases, there is no way to find out which occurred first. Following a large fire, that equipment often shows severe fire damage. All that is left is many loose cooper and steel parts in addition to some large globs of aluminum in a steel box. No useful information can be obtained from the examination of such a box. This author has seen many fire investigators taking many detailed photographs of such equipment as well as pointing to it as the cause of the fire without any evidence except that it was in the fire debris. In such cases, evidence of arcing is just as valuable as evidence of charred wood; it proves that a fire has occurred... a fact that is already known since the fire debris are under investigation.

Figure 12 shows a duplex receptacle that emits a considerable amount of flames. This occurred in a research laboratory. This receptacle was protected by a normal, properly functioning circuit breaker. This happening occurred naturally without any tampering and during the course of normal operation. The exact process that lead to this happening is unknown. However, most likely, for some reasons, such as that caused by the heating of a loose connection, the Bakelite® became pyrolyzed and arcing resulted. The arcing lasted for some 20 to 30 s. This author is grateful to Mr. J. M. Pelletier from Institut de Recherches de l'Hydro-Québec for sending this photograph.

It is clear that such arcing could lead to a fire depending on the nature of the surrounding combustible materials. It is appropriate to mention that no fire resulted in this case notwithstanding the presence of a wood shelf a few centimetres above the receptacle. Such a picture

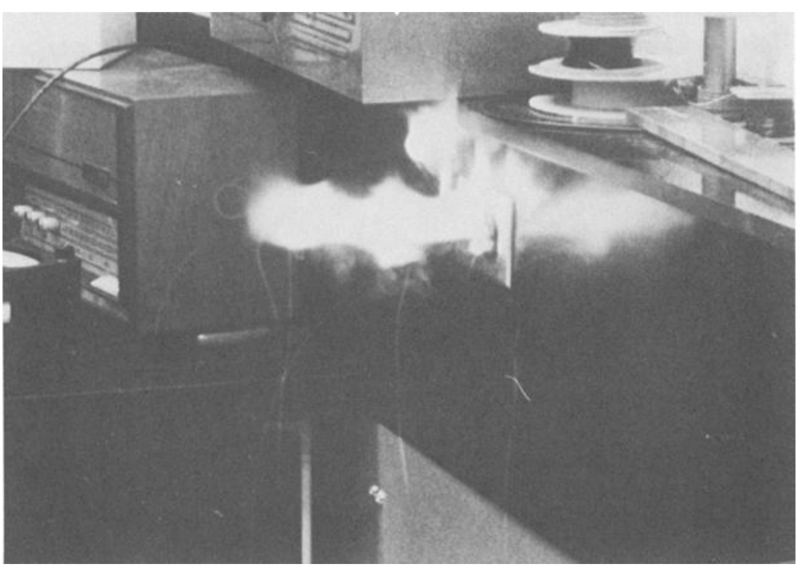

FIG. 12—*Arcing in an electrical outlet.*

is impressive. One must not forget however that some photographic processes may exaggerate the danger. In this case, it is clear that a long exposition time was used as evidenced by the long streaks of incandescent particules. In a long exposition photograph, the luminous effect of the glowing particules is integrated. An incandescent particule appears as a long streak since it is moving.

Discussion

Figures 7 to 11 show typical damages to live cables that were subjected to a fire environment. Clearly this evidence is a normal consequence of a fire. In most fires, some kind of this type of evidence could be found and sometimes by the cartload. Although these results were obtained in a laboratory, they are representative of real life. All factors were comparable to a real fire except for the quantity of materials involved. The materials, the type of cables, the nature of the combustible, as well as the temperatures were as that in a real fire situation.

It is surprising and particularly disturbing to look in many technical journals as well as in books on fire investigation and find similar evidence with the author claiming that the arcing, beading, and damages are characteristics of an electrical fire. This author does not count anymore the number of cases where evidence such as that in Figs. 7 to 11 were used in courts of law by fire investigators to "prove" that a fire was of "electrical origin." In some cases, the "expert" under oath claimed these evidences to be the cause. Occasionally, some "experts" even claimed that they can recognize damages that are the cause from that which are consequences. This author has been confronted by many such cases in both Canada and in the United States. It is frightening to think of the number of cases that went to court and were won with such evidence. Electrical contractors have been sued on such evidence.

There is no doubt that electrical fires do exist. This author has already pointed some causes as well as faulty or badly designed equipment. However, it is a rare occurrence. Electricity is used so often and in so many places that it has to fail somewhere, sometimes. It is however claimed that electrical fires are much less frequent than reported by most fire investigators. Consequences were often taken as the cause. Arcing is just one aspect of the problem, although an important one. Other aspects were discussed in recent articles [*14,15*].

Figure 13 shows two No. 14 copper conductors that were recovered in the fire debris of an old wooden garage. It shows that the two conductors were melted and welded together over a length of about 1 cm. The weld is very good and strong. Except around that particular point where the conductors are welded, the conductors show no evidence of a severe fire. The copper is still malleable and has the normal appearance of copper that had been subjected to a typical fire. The melting is highly localized. It is most unlikely that a wood fire could produce such a localized heating. That is a fair statement. It is known that arcing produces highly localized heating and that is another fair statement. When faced with such evidence, it would seem logical to conclude then that arcing took place and that this is probably the cause of the fire. This is just one step from the conclusion:

> "the only possible cause of ignition is electrical; over a period of years, minute vibrations abraded the insulation away and eventually, arcing took place. The intense heat built up ignited the adjacent combustible materials."

This author has heard that type of argument many times even in courts of law. They have been written many times in books, articles, and fire reports.

The problem with that particular "electrical fire" is that the electricity was disconnected some 20 years before the fire in that garage. It is known for sure then that it was not caused by electricity (lightning is excluded in that case). Had electricity been connected, this probably would have been another case of "electrical fire." As usual, electricity would have been guilty until proven otherwise. In fact, it should be the reverse. An electrical fire should be

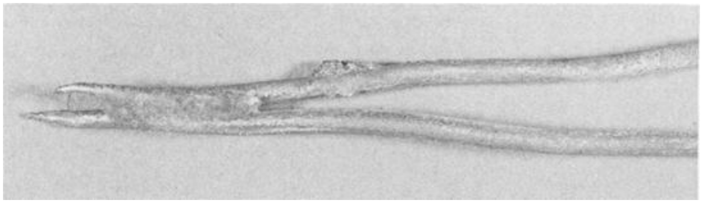

FIG. 13—*Welded copper conductors from a fire scene.*

declared as such only when evidence is brought forward. The mere evidence that some electrical equipment was present at a fire scene is no reason to point electricity.

What is then the cause of the melting shown in Fig. 13 if it is neither caused by electricity nor that the fire has reached a temperature higher than the melting point of copper? An easy answer—and a fair one—will be to let anyone who claims that melting to be due to electricity to prove his point. In this case it is easy. It is due to molten aluminum that had come into contact with the conductors. Molten aluminum migrates in the copper conductors and lowers the melting point of the resulting alloy. That melting point can be as low as 548°C which is appreciably lower than that of aluminum (660°C) or copper (1083°C). Such melting and alloying is easy to produce and is a normal consequence of most fires where molten aluminum can come in contact with copper conductors [*14*].

Although this phenomenon is well-known by metallurgists, it has not been recognized by the fire investigators. Figures 14 and 15 give other examples of the severe attack that molten aluminum can have when it comes into contact with copper. A No. 14 copper conductor can be completely dissolved in a matter of less than 1 min depending on the conditions. This severe attack of copper has been interpreted wrongly as a result of arcing, or more often as a result of electrolytic corrosion. Again, it is bewildering to think of the number of fires where electricity was pointed to as the cause on evidence such as that of Figs. 13 through 15. On occasion, melting and attack such as that in Fig. 13 was described as a result of "unnatural fires and probable use of accelerants."

Evidence such as that shown in Figs. 7 to 11 and 13 to 15 have all at one time or another been used as "solid proof" of an electrical fire. Numerous journals and books have shown similar pictures with comments such as:

1. The beading and arcing is characteristic of an electrically caused fire.
2. Only an electrical fire could cause that type of damages.
3. Examination of the conductors lead to positive proof that the arcing is the cause of the fire.
4. The only possible cause of the fire is electrical in nature.

It is recalled that, in all of these cases, electricity was not the cause of the ignition. In fact, electricity was not even connected in some instances. This author set the fire in most of these cases with a match in presence of some combustible materials. All these evidences are nor-

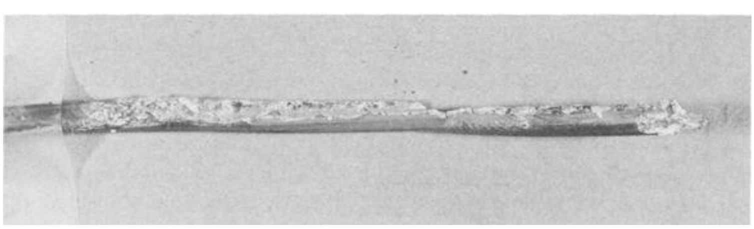

FIG. 14—*A No. 10 copper conductor dipped into a bath of molten aluminum.*

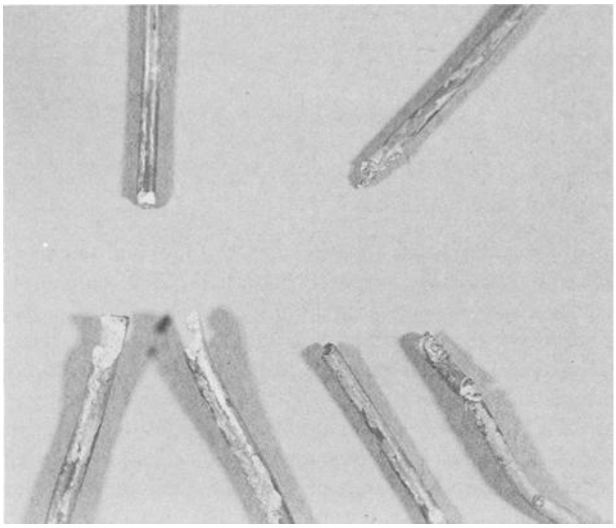

FIG. 15—*Nos. 14 and 12 copper conductors from aluminum armored cables subjected to a fire environment.*

mal consequences of most fires and can often be recovered by the cartload in some fire scenes. The investigator who finds such evidence should continue his search to determine the cause and point of origin. In most instances, this evidence just tends to prove that a fire has occurred for whatever the reason. The value of such evidence is about as good as that of a piece of charred wood.

A Case Study

Figure 16 shows a 14/2 NMD cable that was recovered from the fire debris of a fire which engulfed a 700-m^2 wooden barn structure. The loss was over $100 000. Examination of the calcination pattern could not furnish accurate information as to the point of origin. From that information alone, the point of origin was in fact an area of about 200 m^2. Information from a witness reduced that area to about 40 m^2. The evidence shown in Fig. 16 was found in that area. With such evidence, many fire investigators will suspect or blame electricity as the cause. To make things even worse, that particular cable was installed 40 h before the fire. It was used to feed an 1/2-HP ventilation motor. These two pieces of circumstantial evidence are quite strong. One or the other of these evidences have often been used alone to sue an electrician. The combination of these two evidences should make the case ironclad.

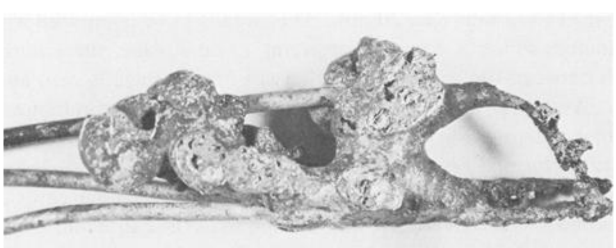

FIG. 16—*A 14/2 NMD cable recuperated from a barn fire.*

There are however a few problems with that evidence. Some of them are as follows:

(1) similar evidence is often found on a fire scene and is known not to be the cause of the fire;

(2) occasionally, much of such evidence could be recovered at a single fire scene, often far from the area of origin; and

(3) years of testings have not lead to a single case where electrical abuses produced similar evidence as the cause of the fire.

Further investigation revealed that an aluminum heat radiator weighing about 400 g was within half a metre of the evidence shown in Fig. 16. Part of that radiator was melted by the fire. Visual inspection of the evidence shown in Fig. 16 suggests that parts of the metal has the color of aluminum-copper bronze. The glob was cut and polished. Examination under a microscope revealed some aluminum phases. Clearly there was also melting of copper. That problem was discussed in Ref *14*.

The cause of this fire is unknown to this author. It is appropriate to mention that further investigation revealed that, in the same area, an infrared heat lamp was used to provide heat for newly born piglets. Wood shavings were used as a floor mat for the piglets. Although it is not known if that is actually the cause, it would seem that such a cause is much more probable than electricity. Surely, electricity is not the only possible cause of that fire. In fact, it is not even the most probable cause.

Another "sure case of electrical fire" is no longer so. In the statistics, it must be deleted from the list of electrical fires and transferred to the column of unknown causes. If the fire investigators were more prudent before classifying a fire as being due to electricity, it would be noted that the percentage of electrical fires is very low. Likewise, the number of unknown causes will increase drastically. Many of these "electrical fires" should have been classified as unknown since no evidence was presented except that electrical wiring was present at the fire scene. It is recalled that a fire is an extremely complex phenomenon.

Circumstantial evidence pointed to electricity as the cause of the fire just discussed. Finding damaged cables is nothing unusual; they are found in most fires even around the point of origin, if not particularly around the point of origin. That should never be used as proof of an electrical fire unless other strong facts point in that direction. The above field case may suggest that the author made every possible effort to disprove that electricity was the cause of the fire. The fact is that the author was retained to establish a possible relation between the electrician's work and the fire for subrogation purposes. The cause of the fire was not determined and it was supported as such notwithstanding the circumstantial evidence pointing to electricity. Note that further investigations disclosed circumstantial evidence that pointed toward other causes.

It was mentioned that this author has never succeeded in reproducing damages such as those in Fig. 16 as the cause of a fire. There is good scientific evidence that suggests that this may be impossible although it is difficult to prove. An arc follows a very thin gaseous conducting path. Every arcing test that was conducted left the conductors with small beaded ends or, occasionally, with a thin short circuited path between the conductors. The short circuit path in Fig. 16 is about 5 by 20 mm. This area is to be compared with the section of one of the conductors which is 2 mm^2. For arcing to take place, there must be no metallic conducting path between the conductors; otherwise, the voltage is zero and arcing cannot start or continue. As soon as a small conducting path between the conductors is formed, then no further arcing is possible. Furthermore, the protective device opens the circuit as soon as a conducting path is formed assuming any reasonable protection.

This field case was not selected to prove a point. Dozens of other cases could have been used. Cases are known where electricity was pointed to as the cause and later on it was found that the cause was entirely different such as: electricity had been disconnected for months or use of 15 L of naphtha "excite" electricity.

Conclusion

Fire investigation is difficult and electrical fires present a particular challenge to the fire investigator. It is all too easy to mistake normal consequences of fires as causes. In this article, it was shown how difficult it is to start a fire by electrical means. Electrical damages that were consequences of a fire were shown for many particular instances. The fire investigator is cautioned against some of the evidence that is often used to point to electricity as the cause while, in fact, they are normal consequences.

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