An Analytical Study of Some Physical Properties of Wire and Cable Samples Collected from Older Homes

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Abstract
This study describes a unique opportunity to measure certain electrical, mechanical, combustibility, and chemical composition characteristics of wire and cable conductor insulation collected from older homes from across the United States. Detailed information about the age, building location, type of conductor, and use conditions within the home enabled inferences to be made about the effects of age and usage on various residential wiring infrastructures. Comparisons between older thermoset rubber and more recent thermoplastic materials are also made.

Background
The Fire Protection Research Foundation (FPRF) of Quincy, Massachusetts, in cooperation with several manufacturers of electrical equipment, insurance companies, testing laboratories, and the U.S. Consumer Product Safety Commission, is sponsoring a multi-year Residential Electrical System Aging Research Project. The goal of this project is to improve residential electrical fire safety by more thoroughly understanding the effects that aging may have on the safety of electrical system components. One aspect of this project is to characterize the condition of various age groups of residential electrical components by surveying, recovering, and analyzing representative samples of actual installed wiring systems, wiring devices, and similar distribution and utilization equipment.

With the help of qualified electrical volunteers from across the U.S., older homes ready for demolition are being identified for this study, and when permission is granted to access these buildings, the volunteers are called upon to photo-document and harvest various aspects of the building's electrical system for further study in the laboratory. The homes generally range in age from 40 to 90 years old. Some history about the house, such as age, location, renovations, etc. is also obtained when available. The building's wire and cable system is generally subjected to a thorough visual examination and dielectric testing as part of the basic study.

Between 2004 and 2006, electrical components were harvested from 11 different houses. In addition, wire and cable samples from 15 additional houses were given to the study. This paper describes an additional analytical study that was conducted on these old wire samples to determine some of the physical properties of the wire insulation after years of service in the house.

Samples and Nomenclature

Each sample was identified by a unique designation using the format XX-Y-Z. XX-Y represents one or two letters followed by a number to identify the specific house or other source from which the sample was obtained. The suffix -Z is a sequential number to represent samples of different wiring systems from the same house or source, or similar samples taken from different locations within the house.

The wire samples were generally from a nonmetallic or armored cable wiring system, or individual conductors that were part of a knob-and-tube system, or installed in metal conduit or tubing. The age of the wire was often known from the age of the building or other information provided by those involved in the harvesting or obtaining of the wire. Other estimates of age were made using the following criteria. Thermoset rubber insulated conductors were generally of a vintage before 1960. Thermoplastic insulated conductors were generally of a vintage after 1950. Nonmetallic cable with a cloth braid jacket was generally of a vintage before 1970. Nonmetallic cable with a thermoplastic jacket was generally of a vintage after 1960. Nonmetallic cable with a grounding conductor was generally of a vintage after 1962. Armored cable with an aluminum bonding wire was generally of a vintage after 1959.

Samples were obtained from St. Paul Travelers Insurance that were taken from investigations on various older houses that had been involved in insurance claims; President Woodrow Wilson's house in Princeton, New Jersey; and residential structures in the Birmingham, Alabama; Chicago, Illinois; and Milwaukee, Wisconsin areas. The estimated age of the samples ranged from 15 to 85 years old. Details on the samples including wire size and conductor insulation information can be found in Appendix A.

Testing of Wire Insulation

The following tests and analysis were conducted on the recovered wire samples:

1. Dielectric Test
2. Bend / Dielectric Test
3. Ultimate Tensile Strength and Elongation Measurement
4. Limiting Oxygen Index Measurement
5. Oxygen Bomb Calorimeter Test
6. FT-IR Measurements
7. Thermogravimetric Analysis

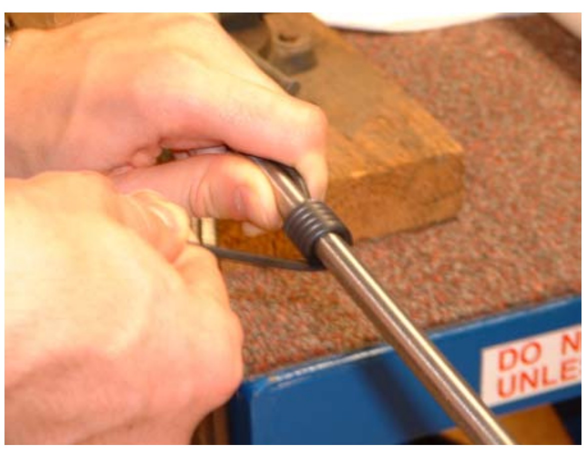
1. <u>Dielectric Test</u> - Dielectric tests were conducted on 2 ft of unaltered samples to determine the effect of aging on the wire insulation and its ability to carry power and temporary transient voltage surges without experiencing a dielectric

breakdown. The middle one-foot of the wire was wrapped tightly in aluminum foil. The dielectric test voltage was applied between the conductor and the aluminum foil. The voltage (ac) was first increased from zero to 5 kV at a rate of 500 Volts per minute, and then held constant for one minute. If no breakdown occurred, the voltage was then increased from zero to 20 kV at a rate of 500 Volts per minute. If dielectric breakdown occurred at less than 20 kV, the potential at dielectric breakdown was noted.

2. Bend / Dielectric Test - Bend tests were conducted to analyze the brittleness of the insulation as may have occurred because of the natural aging process and exposure to the ambient environment. Two feet of unaltered wire was used. For this test, the wire was bent around a mandrel of a diameter as indicated in table 1. Each specimen was tightly wound for six complete turns onto the mandrel. The winding was done at a rate of about 3 seconds per turn, and successive turns were in contact with one another. Following this the wire was examined under a microscope to check for crazing lines and stress whitening, which are precursors to cracking and embrittlement. The two-foot sample was then immersed in steel shot and subjected to an ac dielectric test between the conductor and the shot. The voltage was first increased from zero to 1.5 kV at a rate of 150 Volts per second, and then held constant for one minute. If no breakdown occurred, the voltage was then increased from zero to 20 kV at a rate of 500 Volts per second. If dielectric breakdown occurred at less than 20 kV, the potential at dielectric breakdown was noted.

Table 1

Conductor Size (AWG)	Dia. of Mandrel (Inches)
14	0.313
12	0.375
10	0.563
8	0.688
6	1.250

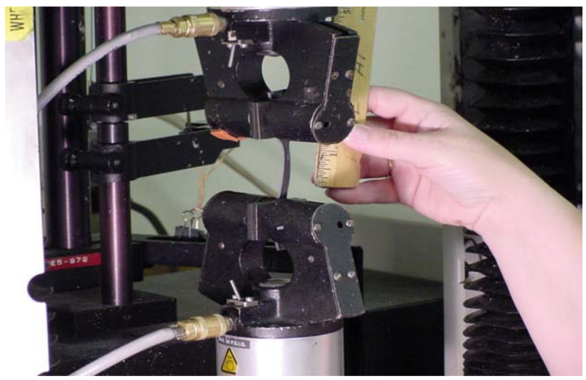


Bend Test Sample

3. Ultimate Tensile Strength and Elongation - Ultimate tensile strength (UTS) and elongation tests using a mechanical tensile strength tester were conducted to compare the mechanical properties of the various samples and the effect of aging on the brittleness of the sample. Test samples consisted of the wire insulation with the conductor removed. The elongation rate was 20 in/min, and the jaws began at a distance of 4 in. The percent elongation was measured by detecting the change in jaw distance from the initial 4 in. value to the final distance recorded when the sample fractured[1]. The UTS was calculated by recording the maximum load in lbf and dividing that value by the area of the insulation. The area was calculated using the following equation,

$$A = (pi / 4) \times (D^2 - d^2),$$

where "A" is the cross-sectional area of the specimen in square inches, "D" is the outer diameter of the insulation in inches, and "d" is the diameter of the conductor in inches.



Tensile Strength Tester

4. Limiting Oxygen Index - Limiting oxygen index (LOI) tests were conducted to determine the minimum oxygen concentration necessary to support combustion in accordance with ASTM D2863 [1]. Ambient oxygen concentration was varied by precisely controlled combination with nitrogen. LOI tests were conducted on unaltered wire by using a methane torch to ignite the wire. If the flame produced a candle-like burn that did not appear as though it would extinguish, the concentration of oxygen was reduced by 1%. If the flame extinguished itself, the concentration of oxygen was increased by 1%. The critical value for the oxygen index concentration was determined to be the oxygen concentration range where the flame extinguished at the lower concentration and produced a candle-like burn at the higher concentration. The conductor was left in the insulation to maintain sample rigidity.

[1] Standards for wire insulation often specify that gauge marks be placed on the insulation spaced two inches apart, and that elongation be measured as the increase in distance between the gauge marks. For the tests described here, elongation was determined by detecting the change in jaw distance from the initial 4-inch value. Review of the plotted elongation data showed that slippage of the sample in the jaws was not occurring, and that the results likely would not have differed significantly from the traditional gauge mark method.

Oxygen Index Apparatus

5. Oxygen Bomb Calorimeter - Potential heat of the wire insulation was evaluated in accordance with NFPA 259 [2]. The inherent material property heat of combustion was determined from the measured potential heat and the sample mass. Approximately 1.3 to1.5 grams of insulation were tested.

6. FT-IR Measurements – Chemical composition information of the wire insulation was characterized in the solid state using a Nicolet Nexus 470 FT-IR (Fourier transform infrared) with a Golden Gate KRS-5 diamond ATR accessory. Spectral response of the materials was measured from 400 – 4000 cm^{-1} wavenumber range with a 4 cm^{-1} resolution; 32 scans were averaged per recorded spectra.

Nexus 470 FT-IR

7. Thermogravimetric Analysis - Thermogravimetric analysis (TGA) is a technique used to measure changes in the weight (mass) of a sample as a function of temperature. TGA is commonly used to determine polymer degradation temperatures, loss of plasticizer from the conductor insulation, and non-combustible content (typically inorganic filler material). For this analysis, a 40 - 50 mg sample of insulation was placed into a tared pan that is attached to a sensitive microbalance assembly. The sample holder portion of the TGA balance assembly was then placed into a precisely controlled furnace. The balance assembly measured the initial sample weight at room temperature and then continuously monitored changes in sample weight as heat was applied to the sample (to 850°C at a constant rate of 10°C /min).

Thermogravimetric Analyzer (TGA)

Results – Electrical and Mechanical Tests

The results of the electrical and mechanical testing can be found in Appendix B. This includes the dielectric test, bend / dielectric test, tensile strength and elongation testing.

Dielectric testing involves the application of a higher than rated voltage for a specified time in order to determine the capability of insulating material to withstand breakdown. In the case of the dielectric testing (and bend testing) conducted with these older wire samples, the dielectric test potential was taken to 20 kV in order to evaluate the dielectric strength of the wire insulation well beyond its intended rating. The bend testing was conducted with the wire first wrapped around the mandrel, and then subjected to the dielectric test to represent wires that may need to be bent to accommodate wiring to a device or fixture. For the bend and dielectric tests, the wire samples were tested in their as-recovered condition, and after careful removal from the cable from which they originated. For the rubber insulated wires, the braid or wrap was left in place.

Dielectric testing of building wires (600 V) when new, generally only involves test potentials of 2 kV or less in these wire sizes, however, the samples are typically immersed in water. None of the recovered wires experienced a breakdown at less than 2 kV for the dielectric test. In general, the thermoplastic samples did better than the rubber samples, as most all of the thermoplastic samples were able to experience 20 kV without breakdown. Three samples, IL-2-2, P-2-1, and P-3-2 experienced dielectric breakdown at less than 5 kV. However, sample P-3-2 was the improper use of AC cable outdoors, and the other two samples were all over 80 years old.

The bend test added another element to the dielectric test in that the sample was bent (wrapped) around a mandrel prior to the dielectric test. A common occurrence with older wires is that throughout the years they may get manipulated and bent when receptacles, switches, luminaires, etc. are replaced. As expected, breakdown potentials were lower because of the bending, although many samples, especially the thermoplastics, performed very well even after almost 50 years of service in the field. Only one sample experienced a breakdown at less than 2 kV as a result of the bend test. That sample, P-2-1, was from an 80 year old knob-and-tube system found in an attic in Alabama. That sample had visible signs of exposed conductor after the bending. However, another approximate 80 year old knob-and-tube system, sample SP-1-14, withstood over 20 kV as a result of the bend test. The following photos illustrate this occurrence.


Sample P-2-1


Sample SP-1-14

Tensile strength and elongation testing are mechanical tests to show the effects of age and brittleness on the sample. These mechanical tests were conducted with the wire insulation removed from the conductor, and with the rubber insulation, the braid or wrap was also removed. With two samples, IL-1-3 and WI-1-3, the insulation could not be removed from the conductor without damaging the sample. Several samples (AL-1-1, AL-2-3, P-2-1, P-3-1, P-3-2, SP-1-10, WI-1-2, and WW-1-2) were too brittle to be tested in the tensile strength tester.

Older standards for rubber wire, such as UL44, *Rubber-Covered Wires and Cables* [3], had requirements for physical properties of rubber insulation before aging that specified a minimum elongation of 200% and a minimum tensile strength of 500 pounds per square inch (psi). None of the samples tested with rubber insulation were able to attain an elongation of 200%. The ultimate tensile strength of the wire with rubber insulation was generally about 500 psi or less. Standards such as UL83, *Thermoplastic-Insulated Wires* [4], had minimum properties for unaged thermoplastic of 100% for elongation and 1,500 psi for tensile strength. All of the samples tested with thermoplastic insulation had elongations of greater than 175%, and most were well over 200%, and tensile strengths well above 2000 psi. The standards typically required that aged samples of rubber and thermoplastic insulation have physical properties of at least 60 – 75% of the unaged properties.

Results – Combustibility Tests

The results of the combustibility testing, including the oxygen bomb calorimeter tests for measurement of heat of combustion, and the limiting oxygen index testing, can be found in Appendix C. These tests are not normally conducted as routine tests for the certification of wire and cable insulation. The data can, however, indicate changes or trends as a result of fillers, and other additives.

The heat of combustion, as determined by the oxygen bomb calorimeter, varied from about 6000 to 12000 BTU/lb for the insulation materials involved. The limited oxygen index testing yielded lower oxygen concentrations ranging between 20 – 40% to self-sustain open-flame combustion of the insulation material.

Results – Chemical Composition Tests

Chemical composition as characterized by FT-IR and thermogravimetric analysis (TGA) has been completed, however, interpretation of the resulting data has not been completed yet.

Analysis of the electrical, mechanical, and combustibility responses to differentiate the effects of aging, chemical composition, and the corresponding correlation between the two factors will be the subject of a forth-coming report.

Summary of Results Versus Age of Wire Sample

Figures 1 and 2 show the results of the dielectric and dielectric / bend tests respectively when plotted versus age of the wire. The trends clearly show a reduction in dielectric strength and bend strength with age; however, this may be largely due to the inherent property characteristic differences between older rubber insulations and newer thermoplastic insulations. In general, thermoplastic insulations performed very well with age.

Fig. 1 - Dielectric Test Results vs Age

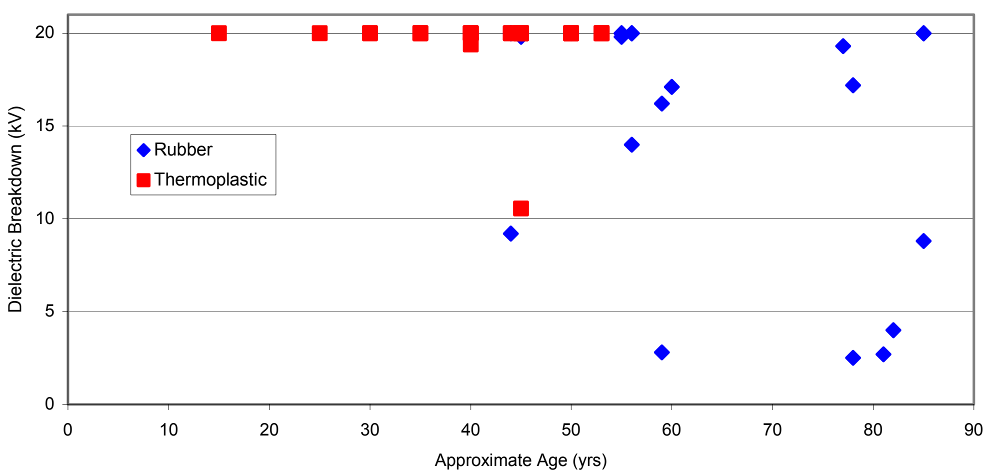
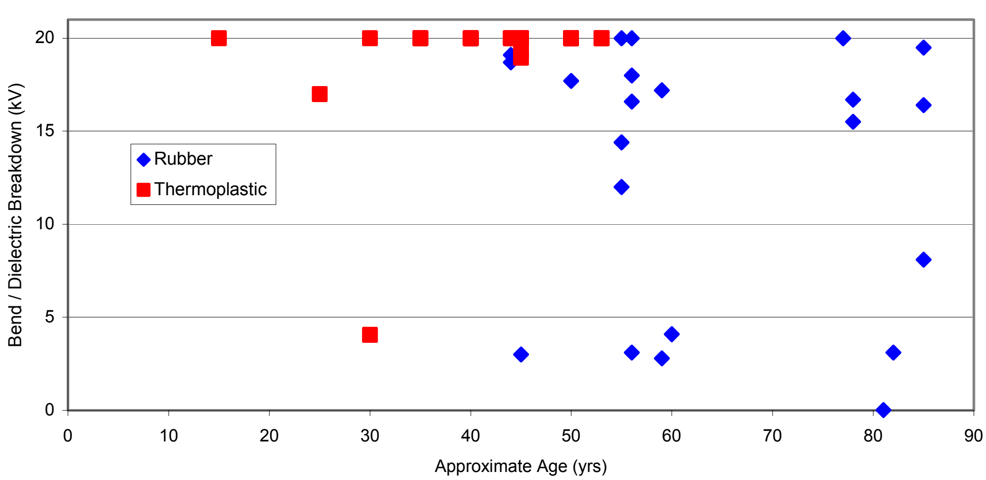


Fig. 2 - Dielectric/Bend Test Results vs Age



Figures 3 and 4 show the results of the ultimate tensile strength and elongation tests respectively when plotted versus age of the wire. Very clear distinctions are evident between thermoplastic and rubber samples. Although the elasticity of many of the older rubber samples was quite low, others appear to have retained much of their original strength, even with age. As with the dielectric and bend tests, the thermoplastic samples performed very well, with little if any loss of elasticity with age.

Fig. 3 - Ultimate Tensile Strength vs Age

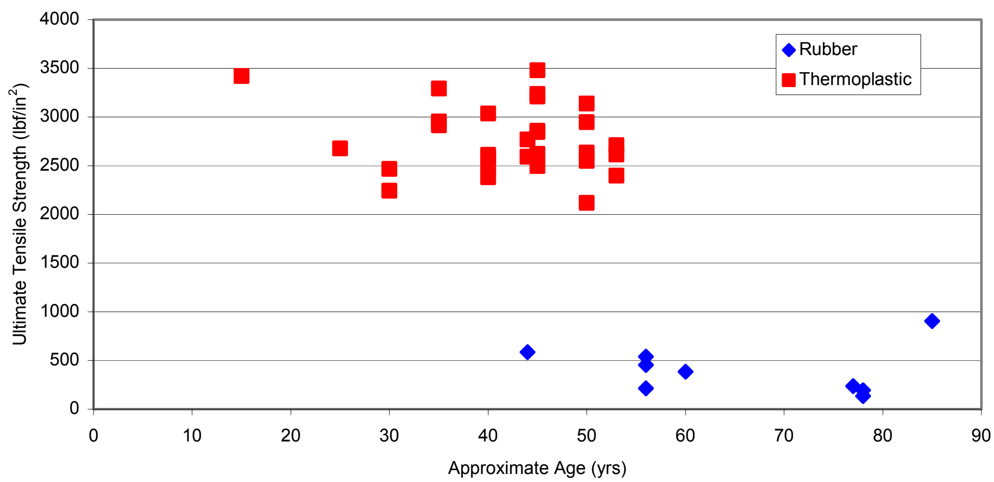
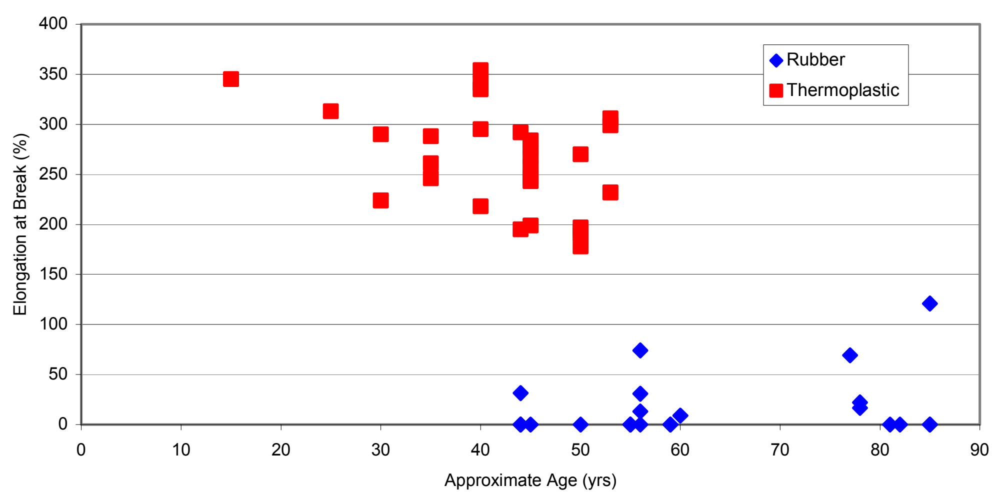


Fig. 4 - Elongation vs Age



Figures 5 and 6 show the results of the limiting oxygen index measurement and oxygen bomb calorimeter test when plotted versus age of the wire. Trends in this combustibility data are less conclusive than with the electrical and mechanical response data. Differences between the thermoplastic and rubber samples may again be due to the inherent differences in the physical proprieties of the two different materials.

Fig. 5 - Limiting Oxygen Index vs Age

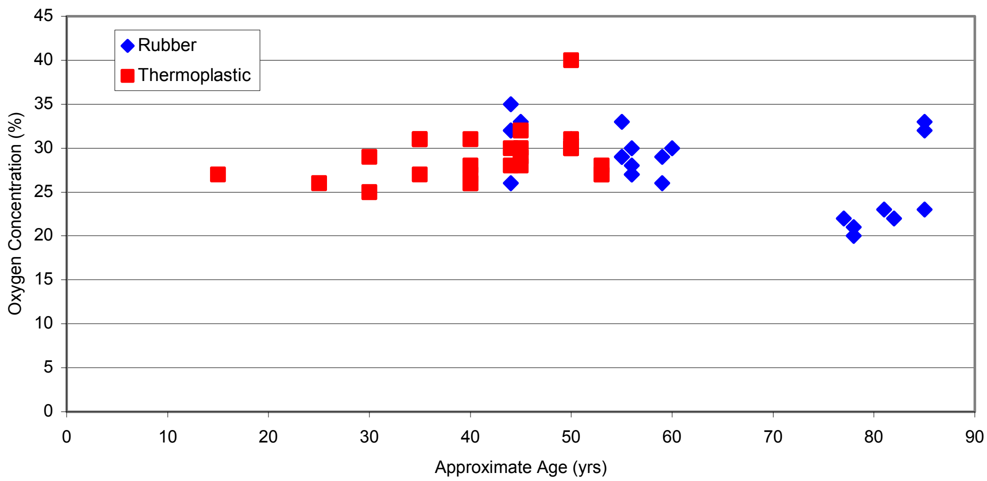
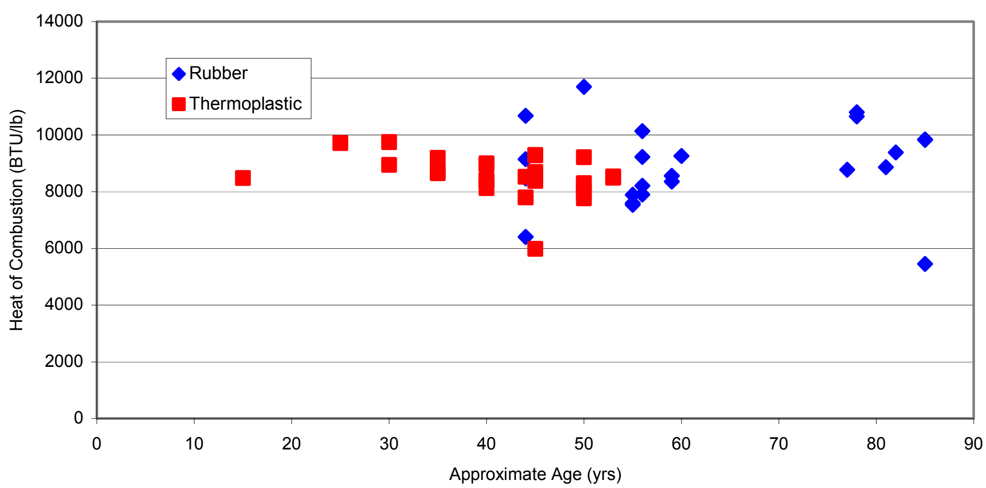


Fig. 6 - Heat of Combustion vs Age



Samples AL-4-1, AL-4-2, and AL-4-3 were identical wire samples taken from the same house in Alabama, but from different locations within the house (bathroom, garage and attic). The samples were No. 12 AWG, 30 mils thermoplastic insulation, and about 50 years old. These different samples can represent different aging conditions, such as temperature extremes, humidity, condensation, etc., within the same building. The tables 2 and 3 summarize the test results from these samples.

Table 2 – House AL-4 Thermoplastic Insulated Wire

	Bend Test	Dielectric Test	Elongation	Ultimate Tensile Strength	Heat of Combustion	Limiting Oxygen Index
Sample ID / location	Breakdown (kV)		% at Break	lb/in2	BTU / lb	% Oxygen
AL-4-1 / bathroom	20+	20+	232	2399	8509	26-27
AL-4-2 / garage	20+	20+	306	2615	8489	27-28
AL-4-3 / attic	20+	20+	299	2709	8537	26-27

Similarly, Samples IL-1-1 and IL-1-2 were identical wire samples taken from the same house in Illinois, but from different locations within the house (attic and bedroom). The samples were No. 14 AWG, 60 mils rubber insulation, and about 80 years old. The following table summarizes the test results from these samples.

Table 3 – House IL-1 Rubber Insulated Wire

	Bend Test	Dielectric Test	Elongation	Ultimate Tensile Strength	Heat of Combustion	Limiting Oxygen Index
Sample ID / location	Breakdown (kV)		% at Break	lb/in2	BTU / lb	% Oxygen
IL-1-1 / attic	16.7	16.0	17	135	10803	20-21
IL-1-2 / bedroom	15.5	17.2	22	195	10660	19-20

Neither of these two examples of identical samples from different locations within the house shows noticeable differences in electrical, mechanical or combustibility characteristics of the wire insulation within the same building. The attic area is expected to be the harshest environment with respect to temperature extremes, as living areas within the house are likely temperature controlled most times of the year.

Further analysis of the test responses to the effects aging, chemical composition, and their corresponding correlation will be the subject of a forth-coming report.

Conclusions

Many houses built over the last 100 years continue to operate with an electrical system infrastructure that may have been original to the building, or at least significantly older than the more modern appliances and furnishings used within the home.

Rubber insulated wires, typical of the 1950s vintage and earlier, can still perform well in many residential environments and expected use conditions. Care, however, should be taken to adequately inspect these older wiring systems for damage, especially where subjected to bending, abrasion, or harsh usage over the years.

Thermoplastic insulated wires, typical of the 1950s vintage and later, generally continue to perform with excellent results, even after 50 years or more of service in the home. The electrical and mechanical characteristics of these wires appear to be exceeding even the original expectations of performance after aging and normal use.

Wire and cable systems that have been improperly installed, such as those intended for indoor use only, but installed outdoors, can show signs of aging and deterioration well beyond what should be expected.

Acknowledgements

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References

[1] ASTM D2863, *Standard Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-like Combustion of Plastics,* American Society for Testing and Materials (ASTM International).

[2] NFPA 259 *Standard Test Method for Potential Heat of Building Materials*, National Fire Protection Association.

[3] UL44, *Rubber-Covered Wires and Cables*, Underwriters Laboratories Inc., 3rd Edition, March 1939.

[4] UL83, *Thermoplastic-Insulated Wires*, Underwriters Laboratories Inc., 4th Edition, April 1963.

Appendix A

Samples AL-1 were taken from a house in the Birmingham, Alabama area that was built in 1960. Sample AL-1-1 was from a nonmetallic cable approximately 45 years old recovered from the attic. Sample AL-1-2 was from a nonmetallic cable approximately 15 years old recovered from the cellar.

Samples AL-2 were taken from a house in the Birmingham, Alabama area that was built in 1920. Samples AL-2-1 and AL-2-2 were from different types of nonmetallic cables approximately 45 years old recovered from the attic. Samples AL-2-3 and AL-2-4 were different types of individual conductors, possibly knob-and-tube, that may have been original to the house and 85 years old, recovered from an unknown location.

Samples AL-3 were taken from a house in the Birmingham, Alabama area that was built in 1962. Sample AL-3-1 was from a nonmetallic cable approximately 44 years old recovered from the attic. Sample AL-3-3 was from a nonmetallic service entrance cable approximately 44 years old. Sample AL-3-4 was from a nonmetallic cable, Type UF, approximately 30 years old recovered from the service panel.

Samples AL-4 were taken from a house in the Birmingham, Alabama area that was built in 1953. Samples AL-4-1, AL-4-2, and AL-4-3 were from nonmetallic cables approximately 53 years old recovered from the bathroom, garage and attic respectively.

Samples AL-5 were taken from a house in the Birmingham, Alabama area that was built in 1927, but probably not wired until the 1940s or 1950s. Samples AL-5-1, AL-5-2 and AL-5-4 were from nonmetallic cables approximately 50 years old recovered from the attic, crawl space, and well house respectively. Sample AL-5-3 was from a nonmetallic service entrance cable approximately 55 years old recovered from the outside meter socket.

Samples IL-1 were taken from a house in the Chicago, Illinois area that was built in 1928. Samples IL-1-1 and IL-1-2 were from armored cables approximately 78 years old recovered from the attic and bedroom respectively. Sample IL-1-3 was from an armored cable approximately 50 years old (but possibly older) recovered from the basement.

Samples IL-2 were taken from a house in the Chicago, Illinois area that was built in 1922. Sample IL-2-1 was individual conductor installed in metal tubing approximately 35 years old recovered from the basement. Sample IL-2-2 was from armored cable approximately 82 years old recovered from the attic.

Samples P-2 were taken from a house in the Chicago, Illinois area that was built in 1950. Sample P-1-1 was from armored cable approximately 35 years old recovered from outdoor receptacles. Sample P-1-2 was individual conductor installed in metal tubing approximately 56 years old recovered from the outdoor meter. Samples P-1-3, P-1-4, and P-1-5 were from armored cable approximately 56 years old recovered from the attic, basement, and inside wall respectively.

Samples P-2 were taken from a house in the Birmingham, Alabama area that was built in 1925. Sample P-2-1 was from a knob-and-tube system approximately 81 years old recovered from the attic. Samples P-2-2 and P-2-3 were from nonmetallic cables approximately 45 years old recovered from the attic and an unknown location respectively.

Samples P-3 were taken from a house in the Birmingham, Alabama area that was built in 1937. Samples P-3-1 and P-3-2 were from armored cables approximately 59 years old recovered from the attic and outdoors respectively. Sample P-3-2 was improper use of armored cable in a wet location. Samples P-3-3 and P-3-4 were from nonmetallic cables approximately 45 years old recovered from the enclosed back porch.

Samples SP-1 were obtained from St. Paul Travelers Insurance and were taken from various older houses that had been involved in insurance claims investigations. Sample SP-1-1 was from a nonmetallic cable approximately 40 years old recovered from a basement. Sample SP-1-2 was from a nonmetallic cable approximately 25 years old recovered from an attic. Sample SP-1-3 was from a nonmetallic cable approximately 35 years old recovered from a basement. Sample SP-1-4 was from a nonmetallic cable, Type UF, approximately 40 years old recovered from the exterior. Sample SP-1-5 was from a nonmetallic cable approximately 50 years old recovered from the interior. Sample SP-1-6 was from a nonmetallic cable approximately 40 years old recovered from a basement. Sample SP-1-7 was from a nonmetallic cable approximately 50 years old recovered from the interior. Sample SP-1-8 was from a nonmetallic cable, Type UF, approximately 30 years old recovered from a basement. Sample SP-1-9 was from an armored cable approximately 40 years old recovered from the interior. Sample SP-1-10 was from an armored cable approximately 55 years old recovered from a basement. Sample SP-1-11 was from an armored cable approximately 60 years old recovered from the interior. Sample SP-1-12 was from an armored cable approximately 55 years old recovered from a basement. Sample SP-1-13 was from an armored cable approximately 40 years old recovered from the interior. Sample SP-1-14 was from a knob-and-tube system approximately 77 years old recovered from the interior.

Samples WI-1 were taken from a house in the Milwaukee, Wisconsin area that was built in 1962, but portions of the house may have been older. Sample WI-1-1 was from an armored cable approximately 44 years old recovered from the attic. Sample WI-1-2 was individual conductor installed in conduit approximately 44 years old (but possibly older) recovered from an outdoor luminaire. Sample WI-1-3 was from a nonmetallic service entrance cable approximately 44 years old (but possibly older) recovered from the outside meter socket. Sample WI-1-4 was from a nonmetallic cable approximately 44 years old.

Samples WW-1 were taken from a house in Princeton, New Jersey that was the onetime home of President Woodrow Wilson. Sample WW-1-1 was a nonmetallic cable approximately 45 years old recovered from an unknown location. Sample WW-1-2 was from a nonmetallic cable approximately 85 years old recovered from an unknown location.

Appendix A Summary

	Cable / Conductor Information				Conductor and Insulation		
Sample ID	Cable Type (Jacket)(1)	Vintage	Approximate Age (yrs)	Location Recovered From	AWG(2)	Material(3)	Nominal Mils
AL-1-1	NM* (CB)	1960	45	attic	14	R(W)	45
AL-1-2	NM-B	1980s-90s	15	cellar	12	T	30
AL-2-1	NM* (CB)	1950s-60s	45	attic	12	T	30
AL-2-2	NM* (T)	1950s-60s	45	attic	12	T	30
AL-2-3	IC	1920	85	unk	10 (str)	R(B)	45
AL-2-4	IC	1920	85	unk	12	R(W)	30
AL-3-1	NM* (CB)	1962	44	attic	14	T	30
AL-3-3	SE	1962	44	inside service	8 (str)	R(B)	60
AL-3-4	UF (T)	1970s	30	inside service	12	T	30
AL-4-1	NM* (CB)	1953	53	bathroom	12	T	30
AL-4-2	NM* (CB)	1953	53	garage	12	T	30
AL-4-3	NM* (CB)	1953	53	attic	12	T	30
AL-5-1	NM* (CB)	1950s	50	attic	14	T	30
AL-5-2	NM (CB)	1950s	50	crawl space	12	T	30
AL-5-3	SE	1940s-50s	55	outside meter	6 (str)	R(W)	60
AL-5-4	NM (CB)	1950s	50	well house	12	T	30
IL-1-1	AC	1928	78	attic	14	R(B)	60
IL-1-2	AC	1928	78	bedroom	14	R(B)	60
IL-1-3	AC	1950s	50	basement	12	R(B)	30
IL-2-1	IC	1960s-70s	35	basement	12	T	30
IL-2-2	AC	1924	82	attic	14	R(B)	60
P-1-1	AC	1960s-70s	35	outdoor rec'pt	14	T	30
P-1-2	IC	1950	56	outdoor meter	6 (AL) (str)	R(W)	60
P-1-3	AC	1950	56	attic	14	R(W)	30
P-1-4	AC	1950	56	basement	14	R(W)	30
P-1-5	AC	1950	56	inside wall	14	R(B)	45
P-2-1	K&T	1925	81	attic	14	R(B)	60
P-2-2	NM (T)	1950s-60s	45	attic	12	T	30
P-2-3	NM* (CB)	1950s-60s	45	unk	14	T	30
P-3-1	AC	1937	59	attic	14	R(B)	45
P-3-2	AC	1937	59	outdoors	14	R(W)	45
P-3-3	NM* (CB)	1950s-60s	45	back porch	14	T	30
P-3-4	NM (T)	1960s	45	back porch	12	T	30
SP-1-1	NM (CB)	1960s	40	basement	12	T	30
SP-1-2	NM (T)	1980	25	attic	14	T	30
SP-1-3	NM (T)	1970	35	basement	10	T	30
SP-1-4	UF (T)	1960s	40	exterior	14	T	30
SP-1-5	NM* (CB)	1950s	50	interior	14	T	30
SP-1-6	NM (CB)	1960s	40	basement	12	T	30
SP-1-7	NM* (CB)	1950s	50	interior	14	T	30
SP-1-8	UF (T)	1970s	30	basement	14	T	30
SP-1-9	AC	1960s	40	interior	14	T	30
SP-1-10	AC	1950	55	basement	14	R(W)	30
SP-1-11	AC	1940s	60	interior	12	R(B)	45
SP-1-12	AC	1950	55	basement	14	R(W)	30
SP-1-13	AC	1960's	40	interior	14	T	30
SP-1-14	K&T	1929	77	interior	14	R(B)	60
WI-1-1	AC	1962	44	attic	14	R(W)	30
WI-1-2	IC	1962	44	outside luminaire	14	R(B)	45
WI-1-3	SE	1962	44	outside meter	6	R(B)	60
WI-1-4	NM	1962	44	interior	14	T	30
WW-1-1	NM* (CB)	1950s-60s	45	unk	12	T	30
WW-1-2	NM	1910s-20s	85	unk	14	R(B)	60

Appendix A Notes

1 - Cable Type Nomenclature --
NM* - nonmetallic jacket, specific NEC type not marked
NM - Type NM nonmetallic -sheathed cable
NM-B - Type NM cable with 90C conductor insulation
UF - Type UF underground feeder
SE - Type SE service-entrance cable
AC - Armored cable
K&T - Knob-and-tube wiring (exposed)
IC - Individual conductors (e.g.. in tubing or conduit)
(CB) - Cloth braid jacket material
(T) - Thermoplastic jacket material

2 - Conductor material is solid copper unless indicated stranded (str) or aluminum (AL). All conductors with rubber insulation are tinned.

3 - "R(B)" indicates rubber with cloth braid covering. "R(W)" indicates rubber with cloth wrap covering. "T" indicates thermoplastic.

Appendix B

Sample ID	Conductor and Insulation: Approx Age (yrs)	AWG	Material	Nominal Mils	Test Results: Bend Test Breakdown (kV)	Dielectric Test Breakdown (kV)	Elongation % at Break(1)	Ultimate Tensile Strength lb / sq in
AL-1-1	45	14	R(W)	45	3.0	19.8	%	
AL-1-2	15	12	T	30	20+	20+	345	3422
AL-2-1	45	12	T	30	19.3	20+	268	2495
AL-2-2	45	12	T	30	20+	20+	247	2845
AL-2-3	85	10 (str)	R(B)	45	16.4	20+	%	
AL-2-4	85	12	R(W)	30	19.5	20+	121	905
AL-3-1	44	14	T	30	20+	20+	195	2592
AL-3-3	44	8 (str)	R(B)	60	20+	20+	%%	
AL-3-4	30	12	T	30	4.1	20+	224	2468
AL-4-1	53	12	T	30	20+	20+	232	2399
AL-4-2	53	12	T	30	20+	20+	306	2615
AL-4-3	53	12	T	30	20+	20+	299	2709
AL-5-1	50	14	T	30	20+	20+	178	3139
AL-5-2	50	12	T	30	20+	20+	193	2635
AL-5-3	55	6 (str)	R(W)	60	20+	20+	%%	
AL-5-4	50	12	T	30	20+	20+	270	2119
IL-1-1	78	14	R(B)	60	16.7	16.0	17	135
IL-1-2	78	14	R(B)	60	15.5	17.2	22	195
IL-1-3	50	12	R(B)	30	17.7	20+	%%%	
IL-2-1	35	12	T	30	20+	20+	261	3294
IL-2-2	82	14	R(B)	60	3.1	4.0	%	
P-1-1	35	14	T	30	20+	20+	288	2953
P-1-2	56	6 (AL) (str)	R(W)	60	20+	20+	%%	
P-1-3	56	14	R(W)	30	3.1	20+	31	455
P-1-4	56	14	R(W)	30	18.0	20+	74	538
P-1-5	56	14	R(B)	45	16.6	14.0	13	214
P-2-1	81	14	R(B)	60	0.0	2.7	%	
P-2-2	45	12	T	30	20+	20+	258	2623
P-2-3	45	14	T	30	18.9	20+	243	2859
P-3-1	59	14	R(B)	45	17.2	16.2	%	
P-3-2	59	14	R(W)	45	2.8	2.8	%	
P-3-3	45	14	T	30	20+	20+	277	3210
P-3-4	45	12	T	30	20+	10.6	284	3482
SP-1-1	40	12	T	30	20+	20+	354	2506
SP-1-2	25	14	T	30	17.0	20+	313	2677
SP-1-3	35	10	T	30	20+	20+	246	2913
SP-1-4	40	14	T	30	20+	20+	295	2382
SP-1-5	50	14	T	30	20+	20+	191	2549
SP-1-6	40	12	T	30	20+	20+	218	3035
SP-1-7	50	14	T	30	20+	20+	197	2949
SP-1-8	30	14	T	30	20+	20+	290	2243
SP-1-9	40	14	T	30	20+	19.4	335	2611
SP-1-10	55	14	R(W)	30	14.4	19.8	%	
SP-1-11	60	12	R(B)	45	4.1	17.1	9	385
SP-1-12	55	14	R(W)	30	12.0	20+	%	
SP-1-13	40	14	T	30	20+	20+	341	2582
SP-1-14	77	14	R(B)	60	20+	19.3	69	237
WI-1-1	44	14	R(W)	30	18.7	20+	31	584
WI-1-2	44	14	R(B)	45	19.1	9.2	%	
WI-1-3	44	6	R(B)	60	20+	20+	%%%	
WI-1-4	44	14	T	30	20+	20+	292	2771
WW-1-1	45	12	T	30	20+	20+	199	3238
WW-1-2	85	14	R(B)	60	8.1	8.8	%	

Appendix B Notes

Elongation Test - explanation for no data:

% - Sample too brittle for tensile strength measurement
%% - Sample too large for insertion in tensile test machine
%%% - Insulation could not be removed from copper conductor

For notes regarding conductor and insulation information, see Appendix A notes.

Appendix C

	Conductor and Insulation				Test Results	
Sample ID	Approx Age (yrs)	AWG	Material	Nominal Mils	Heat of Combustion BTU / lb	Limiting Oxygen Index % Oxygen
AL-1-1	45	14	R(W)	45	8393	32-33
AL-1-2	15	12	T	30	8474	26-27
AL-2-1	45	12	T	30	5988	28-29
AL-2-2	45	12	T	30	8453	31-32
AL-2-3	85	10 (str)	R(B)	45	9844	32-33
AL-2-4	85	12	R(W)	30	9826	31-32
AL-3-1	44	14	T	30	7799	29-30
AL-3-3	44	8 (str)	R(B)	60	10679	31-32
AL-3-4	30	12	T	30	8949	28-29
AL-4-1	53	12	T	30	8509	26-27
AL-4-2	53	12	T	30	8489	27-28
AL-4-3	53	12	T	30	8537	26-27
AL-5-1	50	14	T	30	9213	38-40
AL-5-2	50	12	T	30	7761	30-31
AL-5-3	55	6 (str)	R(W)	60	7591	28-29
AL-5-4	50	12	T	30	7969	29-30
IL-1-1	78	14	R(B)	60	10803	20-21
IL-1-2	78	14	R(B)	60	10660	19-20
IL-1-3	50	12	R(B)	30	11703	30-31
IL-2-1	35	12	T	30	8725	30-31
IL-2-2	82	14	R(B)	60	9383	21-22
P-1-1	35	14	T	30	8654	26-27
P-1-2	56	6 (AL) (str)	R(W)	60	10136	29-30
P-1-3	56	14	R(W)	30	9228	26-27
P-1-4	56	14	R(W)	30	8212	26-27
P-1-5	56	14	R(B)	45	7905	27-28
P-2-1	81	14	R(B)	60	8860	22-23
P-2-2	45	12	T	30	8377	29-30
P-2-3	45	14	T	30	8669	28-29
P-3-1	59	14	R(B)	45	8356	28-29
P-3-2	59	14	R(W)	45	8554	25-26
P-3-3	45	14	T	30	9294	27-28
P-3-4	45	12	T	30	8693	29-30
SP-1-1	40	12	T	30	8130	27-28
SP-1-2	25	14	T	30	9720	25-26
SP-1-3	35	10	T	30	9192	30-31
SP-1-4	40	14	T	30	8389	26-27
SP-1-5	50	14	T	30	8295	29-30
SP-1-6	40	12	T	30	8395	30-31
SP-1-7	50	14	T	30	8238	29-30
SP-1-8	30	14	T	30	9747	24-25
SP-1-9	40	14	T	30	8940	25-26
SP-1-10	55	14	R(W)	30	7891	28-29
SP-1-11	60	12	R(B)	45	9263	29-30
SP-1-12	55	14	R(W)	30	7539	32-33
SP-1-13	40	14	T	30	9004	25-26
SP-1-14	77	14	R(B)	60	8772	21-22
WI-1-1	44	14	R(W)	30	9150	25-26
WI-1-2	44	14	R(B)	45	8463	31-32
WI-1-3	44	6	R(B)	60	6403	34-35
WI-1-4	44	14	T	30	8529	27-28
WW-1-1	45	12	T	30	9281	31-32
WW-1-2	85	14	R(B)	60	5451	22-23