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Effect of fire-resistant carbonate coating for electric cable safety

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Abstract

Electrical fires occur in electrical power lines, wires, circuit breakers, and on other electrical components. The electrical wiring is the core area in power transmission and is of great importance. The carbonates of alkali and alkaline earth metals to combat the circumstances of an electrical fire with a single standalone metal carbonate or as a combination of two or more carbonate mixtures for determining the ideal mixture combination along with % increase in the temperature at which the electrical cables fires started as well as the % increase in the prolongation time of the electrical cables to catch the fire is studied in this work. The carbonate materials were applied in the inner covering of the electrical cables. Application of these self-extinguishing chemicals as fire retardants produces carbon dioxide emissions as a gas blanket on heating. This CO_2 *release from wire cables increases its ignition temperature and further helps to prolong the time for the cables to catch fire. The study optimal results for 3/29 wire gauge with an applied combination mixture of sodium carbonate and calcium carbonate in a 1:1 ratio by weight revealed a % increase in the ignition temperature and the % increase in time to ignite the electrical cables as 38.39±0.48% and 21.86±8.0% respectively. In addition, for the 7/29 wire gauge cable in a similar ratio, the mixture combination of sodium carbonate and magnesium carbonate shows respective results as 13.02±1.7% and 54.5±1.10% increased.*

KEYWORDS: *Carbon dioxide, Electric cable fires, Fire-extinguishing, Time prolongation, Temperature enhancement*

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INTRODUCTION

Fire is an exothermic chemical reaction that starts when a fuel is mixed with an air-oxygen mixture and is heated to the fuel ignition temperature. This reaction results in the release of heat, light, and various gaseous emissions. These emissions quickly spread around and harm the people's ecosystem, and even lead to the loss of human lives [1, 2]. Once ignited, the fire chain reaction is continuous by its sustained heat energy release in the process of combustion for the next molecule of the fuel and this propagates provided there is a continuous supply of an oxidizer and fuel [3].

Electric cable fires are caused by a variety of factors. Some common causes are when an electrical circuit is overloaded, it generates excessive heat that can damage the insulation on the wires, causing them to ignite. A short circuit occurs when a current travels along an unintended path, usually due to a damaged wire or a faulty electrical appliance. This can generate enough heat to ignite nearby combustible materials. Electrical arcing is another example, it occurs when a high-voltage current jumps across a gap in a damaged or improperly insulated wire[4]. In addition, electrical wiring that is improperly installed or maintained can be a fire hazard. Damaged or frayed wires can generate heat and ignite nearby combustibles. Electrical equipment such as transformers, circuit breakers, and electrical panels can fail due to age, wear and tear, and due to improper maintenance, thus, creates a potential fire hazard. Natural disasters like lightning strikes, floods, and earthquakes can also damage electrical systems and create a fire hazard. Therefore, it's important to note that many electrical fires can be prevented by proper installation, insulation, maintenance, and regular inspections of electrical systems and equipment.

To practice good fire safety habits in preventing electrical cable fires it is very important to ensure that fire retardants are added, and blends are uniformly spread in the polymer covering of the electrical wires. There is a sizable global market for flame retardants. More than 2.25 million tons of flame retardants were consumed globally in 2017. Around 8.39 billion dollars were spent on flame retardants in the global market in 2019. In the year 2030, it is predicted that the size of this industry's global market will increase to about 16.6 billion [5]. A large filler loading is necessary to show a noticeable increase in the polymer flammability resistance. This is crucial in reducing the risk of fires in minimizing the potential damage to the cables [6]. Recently, Sarti et al., 2022 [7] have shown the use of metal carbonates as an effective fire retardant for electrical cables. Mineral fillers are a significant class of fire retardants with numerous inherent sustainable characteristics, such as their manufacturing is a clean process, that causes a reduction in the use of polymers in the cables. Use of carbonate materials on the electric cables produces an inert blanket of CO_2 around the cable wire upon thermal decomposition that cuts off the supply of oxidant which reduces the possibility of fire and thus results in a reduction in human fire injury or death in case of electric cable fires [8, 9].

Fires can be classified into different categories. Fire retardants are substances that are added to flammable materials to reduce their flammability or slow down the spread of fire. The type of fire retardant used to put out a particular type of fire depends on the fuel that causes the fire. Fire due to the burning of wood, paper, cloth, and plastics is classified as class A fire. The flame retardants used in fire extinguishers to put off class A fires are water, foam, and dry chemicals. Examples of common dry chemicals are sodium bicarbonate, potassium bicarbonate, and mono-ammonium phosphate. Fires that involve the combustion of fuel materials like hydrocarbons, oils, and gasoline are classified as class B fire. Carbon dioxide, dry chemicals (as mentioned above), and foam materials (aqueous film-forming foam and film-forming fluoroprotein) are fire retardants used for class B fire. Class C fire is due to the catch of fire in electrical components such as motors, transformers, and electric cables. Flame retardants such as carbon dioxide gas, dry chemicals, and halon are frequently used to extinguish class C fire. Fire due to the burning of flammable metals such as magnesium, sodium, and potassium is classified as class D fire. Dry powders such as sodium chloride and graphite are the flame retardants used to extinguish class D fire. Fires caused by fats and oils used in cooking are categorized as class K fires. Potassium acetate and potassium citrate (wet chemical agents) are used as fire retardants to put off class K fire. It is important to note that different fire extinguishers are designed for different classes of fires, and using the wrong type of extinguisher can make the fire worse. Thus, it is important to be familiar with the different types of fires and the appropriate fire extinguishers to be used for each type of fire[3, 10].

Most flexible cables are constructed of hydrocarbon-based polymers. Because these basic polymers do not have flame retardants and have a high calorific value. The cable producers add chemicals in polymers to make them more suitable and sustainable to use. Polymer cables with added chemicals like halogens, such as chlorine, are especially excellent additions for retarding flame propagation while having no effect on the dielectric characteristics of the polymer, they are employed in both cable insulations and cable sheaths. However, the addition of these halogenated polymers has a detrimental side effect when the electrical cable catches fire, the fire emits these halogens as very poisonous halides that, when mixed with moisture, irritate the eyes, nose, mouth, and lungs. With halogens PVC wires frequently emit huge volumes of noxious smoke. There are also endothermic flame retardants that are sufficiently stable to be integrated into thermoplastics without decomposition, magnesium hydroxide and magnesium carbonates have drawn attention [11]. When combined with polymers, calcium carbonate ($CaCO_3$), a plentiful and inexpensive filler, reduces costs and has moderate benefits on mechanical qualities including increased modulus and impact strength [12].

The inflammation of the electrical cable polymer covering is the primary cause of electrical fires. Therefore, our approach rests on the use of low-cost fire retardants in the polymer coating of electrical cables that release CO_2 when they get heated, which will cut off or reduce the supply of oxygen thus preventing temperatures from climbing too high in the event of a short circuit. Also, the melting of PVC or other coatings is prevented [13, 14]. Figure 1(a) depicts the whole idea of preventing electrical fires by applying fire-retardants on the wires below the polymer covering whereas Figure 1(b) shows the impact in the absence of application of fire retardants on the copper wires.

Therefore, based on the literature review there are two objectives of this research. 1)To investigate the impact and use of several individual carbonate materials and mixtures to extend the time and temperature limit to catch fire and (2) To identify the optimal carbonate material or mixtures that result in the highest ignition temperature and longest time to start a fire.

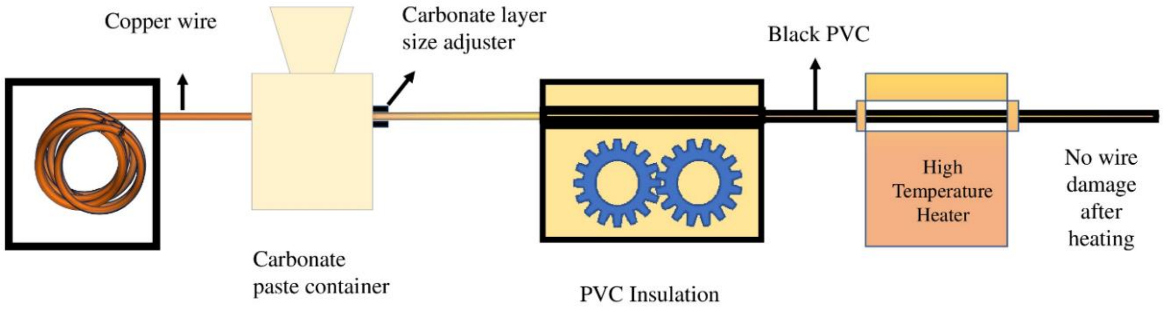

Fig. 1(a): Process of carbonate material coating on electric copper wire to prevent fire on heating

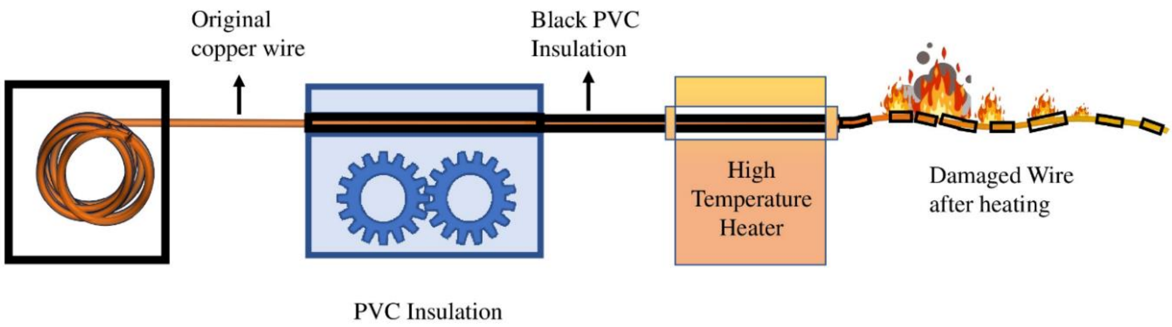

Fig. 1(b): Impact of heat on polymer covering in the absence of fire retardant on the electric copper wires.

The method for the testing of electric cable wires reported in the literature is given in Table 1.

Table 1 Methods used for the analysis of electrical cable properties.

Sr. No	Methods for testing electrical cable properties	References
1.	Analysis of cable mechanical and electrical properties	[15]
2.	Analysis of conductive materials	[16]
3.	Analysis for cables temperature characterization	[17]
4.	Analysis of insulation materials via partial discharges	[18]
5.	Analysis of electric field characterization of cable joints	[19]

EXPERIMENTAL SECTION

Materials

The GM company electric cable wire gauges 3/29 and 7/29 were purchased from local vendors in Lahore Pakistan. All the cables contain 99 percent pure copper wire. The chemicals, sodium carbonate, magnesium carbonate, and calcium carbonate were purchased from the Sigma Aldrich

Pakistan office. A welding transformer unit ranging from 100-500 volts, which can deliver high voltage and current, was purchased from Diamond Pakistan. A digital clamp meter (YF-8030A, China) for current measurement and an infrared thermometer (UT303D, China) were used. A laboratory scale polymer insulation equipment made at the Institute of Chemical Engineering and Technology, Lahore, Pakistan was used for the insulation of the copper wires. The properties of electric cables, wire gauge 3/29 and 7/29 are shown in Table 2.

Table 2 Properties of 3/29 and 7/29 electric cables

Properties	***3/ 29 Electric Cable***	***7/ 29 Electric Cable***
No. Of Strands	***3***	***7***
Strand Diameter	***.029 Inch***	***.029 Inch***
Conductor Type	***Copper***	***Copper***
Insulation Type	***Poly Vinyl Chloride (PVC)***	***Poly Vinyl Chloride (PVC)***
Standard	***BSS-2004 Equivalent 1.5mm² BSS-6004 in Pakistan***	***BSS-2004 Equivalent 2.5mm² BSS-6004 in Pakistan***
Temperature Rating	***-20C° to 70C°***	***-20C° to 70C°***
DC Resistance	***14.03 ohm/km***	***1.27 ohm/km***
Voltage Rating	***250/450V***	***250/450V***
Ampere Rating	***11 Amps***	***21 Amps***

Methods

First, equal cable lengths were cut from 3/29 and 7/29 schedules cable rolls with the help of a cutter then the copper wires were taken out of the polymer covers. The mixture of carbonate chemicals was prepared by using the known weight of carbonates with water and stirred continuously until a paste like consistency was achieved. Then the semi-solid paste was filled into a container and the copper wire passed through it by adjusting its speed through the carbonate paste then carbonated coated wires were passed through a size thickness adjuster hole and a layer of 1.00 mm thickness was maintained. The copper wires were then insulated again with the polymer cable covering using rollers as shown in figure 1a and 1b. After allowing, the electric cables to dry completely, a transformer unit ranging from 100-500 volts, which can deliver high voltage and current, was then used to test the electric cables by allowing the current to pass through the wires. Figure 2(a) shows the schematic view of the electric cables before and after carbonate coating. A clamp meter for current measurement and an infrared thermometer for temperature measurements were then used as shown in Figure 2(b). The recorded data for each test case is then noted for a comparison in each scenario of the chemical mixture applied as individual carbonate or a mixture of two carbonates. A stopwatch was used to note down the time when the fire burning started with a wire. The voltage experimentation is kept constant at 100V (122 ampere) and 500V (152 ampere) for the 3/29 and 7/29 wire respectively. All the carbonate coatings were tested twice. The temperature was measured at the copper electric cables with the help of an infrared temperature measurement gun for the cable's temperature characterization.

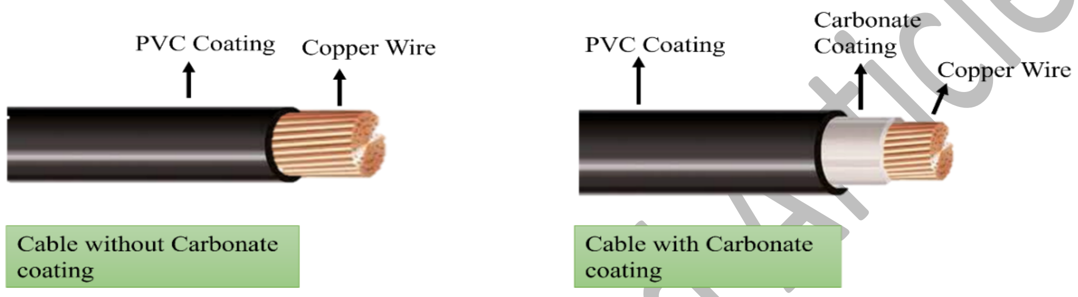

Fig 2(a): Pictorial view of Electric cable wire without carbonate coating (left side) with carbonate coating (right side).

Fig 2(b) A clamp meter (left side) for current measurement and an infrared thermometer for temperature measurements (right side).

Calculation method for percentage increase

The following equation 1 was used to calculate the percentage increase in the ignition temperature and delay in time to catch the fire by the electric cables.

$$\text{Percentage Increase} = \frac{\text{Final temperature value} - \text{Starting temperature value}}{\text{Starting temperature value}} * 100$$

Eq. (1)

RESULTS AND DISCUSSION

Impact of fire retardants on ignition temperature

The 3/29 wire when short-circuited as per method given in the methods section the current passing through the wire was 122 ampere, much higher than the normal 11 ampere rating for the 3/29 cable wire. However, it was noted that when 7/29 wire was short circuited the current passing through the wire was 152 ampere. The percent increase in flame ignition temperature for 3/29- and 7/29-gauge wire in the case of individual chemical application and with the combination of chemical coating is given in Table 3 and Table 4 respectively.

Table 3 Comparison of increase in ignition temperature for 3/29 wire gauge

Sample Designation	*Wire*	*Formulations*	*Results Temp (K)*	*% increase in temperature*
f0	*3/29*	*Free of chemical coating, test of original wire.*	*315.15±2.83*	*0*
f1		*Only Na_2CO_3 coating*	*356.15±1.41*	*13.01±0.79*
f2		*Only $CaCO_3$ coating*	*370.65±3.54*	*17.61±0.09*
f3		*Only $MgCO_3$ coating*	*363.65±2.12*	*15.39±0.51*
fs1		*(50%Na_2CO_3+50%$CaCO_3$) mixture coating*	*436.15±2.83*	*38.39±0.48*
fs2		*(50%Na_2CO_3+50%$MgCO_3$) mixture coating*	*431.15±2.83*	*36.81±0.46*
fs3		*(50%$CaCO_3$+50%$MgCO_3$) mixture coating*	*392.65±3.3*	*24.59±0.10*
fs4		*(30%$CaCO_3$+30%Na_2CO_3+ 40%$MgCO_3$) mixture coating*	*403.65±3.54*	*28.08±0.03*

Table 4 Comparison of increase in ignition temperature for 7/29 wire gauge

Sample Designation	Wire	Formulations	Results Temp (K)	% increase in temperature
F0		Free of chemical coating, test of original wire.	387.65±2.12	0
F1		Only Na_2CO_3 coating	379.65±2.12	2.06±0.01
F2		Only $CaCO_3$ coating	409.15±1.41	5.54±0.30
F3	7/29	Only $MgCO_3$ coating	409.15±4.24	5.54±0.73
FS1		(50%Na_2CO_3+50%$CaCO_3$) mixture coating	432.65±14.85	11.59±4.55
FS2		(50%Na_2CO_3+50%$MgCO_3$) mixture coating	438.65±7.07	13.02±1.70
FS3		(50%$CaCO_3$+50%$MgCO_3$) mixture coating	392.65±0.71	1.29±0.52
FS4		(30%$CaCO_3$+30%Na_2CO_3+ 40%$MgCO_3$) mixture coating	399.65±2.12	3.09±0.02

Both Tables 3 and 4 show an increase in the ignition temperature with the application of metal carbonates in the polymer cable coverings. This is because metal carbonates are not only endothermic in their decomposition process, but also remove heat from the system. In addition, their by-products behave endothermic in nature, a second reason is that many of their decomposed salts are natural fire retardants and can put out a fire flame [20].

In the case of 3/29 wire, a maximum increase in the ignition temperature was noted as *38.39±0.48%* which is when a mixture of (50%Na_2CO_3+50%$CaCO_3$) was applied over the copper electrical wire. Whereas in the case of 7/29 wire when a mixture of (50%Na_2CO_3+50%$MgCO_3$) was applied a percentage increase of *13.02±1.7%* is noted in the ignition temperature. However, when the same amount of carbonate-based fire-retardant mixture of (50%Na_2CO_3+50%$CaCO_3$) was applied on 7/29 wire gauge the percentage increase in ignition temperature came out slightly lower as 11.59±4.55%, but that is with a higher standard deviation which makes this mixture combination also a good candidate as a fire-retardant mixture for 7/29 wire gauge at times. This may be due to less CO_2 release as the decomposition temperature of $Na_2CO_3 > CaCO_3 > MgCO_3$. The intricate link between the carbonate decomposition temperature and the igniting time relies on the electric cable material condition. Electric cable material treated with fire retardant prevents electric cable burning. This is accomplished by several techniques, including the release of fire-retardant gases, the formation of a protective char layer, or the dilution of the flammable gases emitted during burning. Thus, for carbonates, high temperatures may cause them to break down, producing gases like carbon dioxide and their respective metal oxides. This decomposition process can absorb heat from the environment and produce a barrier that inhibits the transmission of heat to the substance, delaying the ignition process. Moreover, the variation in the percent increase in ignition temperature in the case of 3/29 and 7/29 wire gauge, when the same amount of (50%Na_2CO_3+50%$CaCO_3$) was applied was due to the higher heat absorption capacity of $CaCO_3$, as 3/29 wire has less copper in comparison to 7/29 wire so more heat is absorbed by the $CaCO_3$ coating at the given voltage i.e. 100V (122 ampere) [21] in comparison to 7/29 wire gauge me. e. 500V (152 ampere). The 7/29 wire has 7 strands, the increased strand count in the 7/29 cable wire enhances its flexibility, conductivity, and heat dissipation, leading to a lower temperature increase within the wire compared to the 3/27 cable wire[22]. That's why there is a low % increase in temperature in the case of 7/29 electric wire cable with the application of carbonated material compared to 3/29 gauge.

Table 5 and Table 6 show the change in reaction enthalpy of the three chemicals used and the heat capacity of the three oxides resulting from the reaction respectively.

Table 5 Change in reaction enthalpy of the three chemicals used as fire retardants

Sr No.	Chemicals	Reaction	Change in reaction enthalpy
1	Na_2CO_3	Na_2CO_3 (s) → Na_2O (s) + CO_2(g)	320.87 KJ/mole
2	$CaCO_3$	$CaCO_3$(s) → CaO (s) + CO_2(g)	178.78 KJ/mole
3	$MgCO_3$	$MgCO_3$(s) → MgO (s) + CO_2(g)	161.42 KJ/mole

To understand a substance's energy potential, one must understand its enthalpy, which is the heat content released during combustion. Exothermic combustion reactions require more energy to form new bonds than they release, resulting in a negative change in enthalpy. Whereas endothermic combustion reactions absorb energy to decompose the material. This shows that the fire retardancy capacity of $MgCO_3$> $CaCO_3$>Na_2CO_3 respectively [23, 24].

Table 6 The heat capacity of the three oxides resulting from the reaction

Sr No.	Oxides	Heat Capacity (J/mol-K) at Temperature(K)	Heat Capacity (J/mol-K) at Temperature(K)	Heat Capacity (J/mol-K) at Temperature(K)	Heat Capacity (J/mol-K) at Temperature(K)
1	Na_2O	57.6 at 298.15	54.60 at 356	53.4 at 379.5	21.3 at 1000
2	Co	49.9 at 298.15	45.3 at 370.5	42.83 at 409	4.88 at 1000
3	MgO	47.25 at 298.15	43.4 at 363.5	40.7 at 409	5.7 at 1000

The high heat capacity values of the oxides are attributed to the high thermal stability of their respective carbonates and the energy required for their decomposition[25]. The values of the energy absorbed or released per mole at different temperatures are shown in Table 6.

The impact of fire retardants on time to ignite

Table 7 and Table 8 show the data collected by the application of a single or multiple carbonate mixture applied over the copper electrical wire.

Table 7 Comparison of the increase in time to ignite for 3/29 wire gauge

Sample Designation	***Wire***	***Formulations***	***Results Time (Sec)***	***% increase in time to ignite***
f0	***3/29***	***Free of chemical coating, Test of original wire.***	***14.7±0.9***	***0***
f1		***Only Na_2CO_3 coating***	***13.6±0.6***	***(-7.04 ± 2.7)***
f2		***Only $CaCO_3$ coating***	***17.2±0.1***	***17.49±9.7***
f3		***Only $MgCO_3$ coating***	***16.9±1.2***	***14.95±1.4***
fs1		***(50%Na_2CO_3+50%$CaCO_3$) mixture coating***	***17.8±0.3***	***21.86±8.0***
fs2		***(50%Na_2CO_3+50%$MgCO_3$) mixture coating***	***17.1±0.4***	***16.69±6.9***
fs3		***(50%$CaCO_3$+50%$MgCO_3$) mixture coating***	***15.63±1.2***	***6.59±2.12***
fs4		***(30%$CaCO_3$+30%Na_2CO_3+ 40%$MgCO_3$) mixture coating***	***17.8±0.2***	***21.54±8.73***

Table 8 Comparison of the increase in time to ignite 7/29 wire gauge

Sample Designation	***Wire***	***Formulations***	***Results Time (Sec)***	***% increase in time to ignite***
F0	***7/29***	***Free of chemical coating Test of original wire.***	***48.8±0.2***	***0***
F1		***Only Na_2CO_3 coating***	***41.5±0.7***	***(-15.05±1.52)***
F2		***Only $CaCO_3$ coating***	***53.7±1.9***	***9.81±4.85***
F3		***Only $MgCO_3$ coating***	***53.6±0.6***	***9.85±1.1***
FS1		***(50%Na_2CO_3+50%$CaCO_3$) mixture coating***	***68.5±3.5***	***40.2±9.3***
FS2		***(50%Na_2CO_3+50%$MgCO_3$) mixture coating***	***75.5±0.7***	***54.5±1.10***
FS3		***(50%$CaCO_3$+50%$MgCO_3$) mixture coating***	***52.2±0.2***	***6.76±0.04***
FS4		***(30%$CaCO_3$+30%Na_2CO_3+ 40%$MgCO_3$) mixture coating***	***63.5±0.7***	***29.9±1.25***

From Table 7 and Table 8, The data noted shows a percentage increase in time to ignite the electric cable of 3/29 and 7/29-gauge wire respectively, with the application of individual metal carbonates and for a mixture of metal carbonates. An optimal value of 21.86±8.0% time increase was obtained for 3/29 wire gauge when a (50%Na_2CO_3+50%$CaCO_3$) mixture coating was applied to the wire whereas an optimal value of 54.5±1.10% increase in time to ignite the copper wire cable was noted when a (50%Na_2CO_3+50%$MgCO_3$) mixture coating was applied to the 7/29 wire gauge.

It can be further inferred from the experimental work that when only Na_2CO_3 coating was applied to the electric copper wire as fire retardant there is a negative effect on the fire retardation property this is because Na_2CO_3 has poor flame-retardancy that's why we have a limited delay in time to ignite and increase in ignition temperature. The ineffectiveness of the fire-retardant is attributed to the slow release of carbon dioxide (CO_2) and its respective metal oxide during the combustion process[26]. Although Na_2CO_3 can produce these non-combustible byproducts, it does not have the same efficiency or rapid release mechanism as other flame retardants[14].

The mixtures with (50 percent Na_2CO_3 and 50 percent $CaCO_3$) & (50 percent Na_2CO_3 and 50 percent $MgCO_3$) resulted in a higher percent increase in time to ignite the wire than in comparison when a mixture combination of (50 percent $MgCO_3$ and 50 percent $CaCO_3$) is applied. This is because the mixture of $MgCO_3$ and $CaCO_3$ at higher temperatures decomposes into CO_2 and their respective oxides. These oxides in the presence of water turn into hydroxides as Mg $(OH)_2$ and Ca $(OH)_2$. However, Na_2CO_3, which has greater solubility in water is likely to form Na^+ and CO_3^- ions. When this Na_2CO_3 mixture is mixed with any other mixture of $CaCO_3$ or $MgCO_3$ the CO_2 is only released from the mixture by thermal decomposition of Na_2CO_3. The thermal decomposition of a mixture of Na_2CO_3 and $CaCO_3$ takes place at relatively higher temperatures around 800-850ºC (1073.15K – 1123.15K). Whereas the thermal decomposition of a mixture of Na_2CO_3 and $MgCO_3$ takes place at relatively low temperatures around 350-600ºC (623.15K – 873.15K) [27-29].

For carbonates, high temperatures may cause them to break down, producing gases like carbon dioxide. This decomposition process can absorb heat from the environment and produce a barrier that inhibits the transmission of heat to the substance, delaying the ignition process. Depending on the type of carbonate employed and the temperature at which it decomposes, there are unique effects on ignition time. Additionally, careful formulation and optimization of the fire-retardant mixtures can affect the ignition temperature by considering elements like carbonate concentration and particle size. This guarantees that the fire-retardant system protects against combustion effectively[30]. This further explains why (50%Na_2CO_3+50%$MgCO_3$) mixture coating gives a higher percentage increase in ignition temperature and time to ignite the wires in comparison to a mixture coating of (50%Na_2CO_3+50%$CaCO_3$) in the case of 7/29 wire.

During the full combustion of electric wire cables, the flame's color can vary. In some cases, the wires may emit a red/orange glow. The flames ultimately take on the color created by the burning fuel. During partial combustion of electric wire cables, the color of the flame can also vary, but it is often described as a yellowish flame of around 150 mm in length, as observed in experimental testing and evaluation of cable coatings[31].

CONCLUSION

From this research work, it is concluded that coating of an individual carbonate chemical (Na_2CO_3, $CaCO_3$, and $MgCO_3$) or a mixture of these carbonate chemicals on an electric wire can successfully increase the wire ignition temperature or delay the time for an electric wire to catch fire. An optimal increase in ignition temperature and increase in ignition time to catch fire for 7/29 wire schedule was noted with the application of (50%$N_{a2}CO_3$+50%$MgCO_3$) mixture coating as *13.02±1.7% and 54.5±1.10%* increase respectively whereas for 3/29 wire schedule a *38.39±0.48% and 21.86±8.0%* increase in ignition temperature and delay in ignition time was noted when a (50%Na_2CO_3+50%$CaCO_3$) mixture coating was applied. This further shows that the wire type or wire gauge also has an impact on the fire extinguishing results when an individual or a mixture of carbonate chemicals is applied as a fire-retardant material on the electrical wire. It is concluded that an application of the combination of carbonate mixtures of the electrical wire showed better results than the application of an individual carbon coating on an electrical wire for a percentage increase in (1) ignition temperature of electrical wires, (2) time to delay of fires in electrical wires.

FUTURE RECOMMENDATIONS

A better technique needs to be worked out to first coat the copper wires with metal carbonate chemicals, and then with the PVC coating this will boost the effectiveness of the chemical's application method in extinguishing fires. Moreover, a detailed mixing ratio of the carbonate chemicals needed to be studied. Further, a comprehensive study on the use of the inclusion of one or two more salts, specifically Ca and Mg phosphates, along with Ca gluconate. Comparing these with carbonates can provide valuable insights into the diverse effects of different organic salts on coating properties, corrosion resistance, and biocompatibility. This extension could enhance the comprehensiveness of the study and contribute to a more thorough understanding of the potential applications of various organic salts in coating technologies.

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CREDIT AUTHOR STATEMENT

Yousuf Jamal: Supervision, article review and editing

Abid Mehmood: Developed research methodology

Uzair Jan: Data collection and draft writing
Shehroz Ahmed: Data collection and draft writing

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