Study on the Ignition Capacity of Overloaded BVV Wires to Combustibles

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Abstract. To clarify the ignition characteristics of BVV copper wires on different types of combustibles under overload conditions and provide theoretical support for electrical fire investigation and fire safety, this study took 1.5mm² BVV copper wires as the research object. Under the overload condition of 6 times the rated current (108A), the ignition capacity and phenomena of the wires on debris materials (paper scraps, wood chips), fiber materials (cotton yarn, polyester), and foam materials(polyurethane foam, polystyrene foam)were systematically studied through different contact methods including single-sided contact, full wrapping, half wrapping, and 5mm spacing. Key parameters such as temperature change, smoke emission time, ignition time, and combustion duration were collected using thermocouples, high-speed cameras and other equipment. The experimental results show that: for debris materials, the ignition risk of spaced contact is the highest, and wood chips are more easily ignited than paper scraps with stronger combustion persistence, for fiber materials, the ignition risk of full wrapping contact is the highest, and cotton yarn has a lower ignition point and more intense fire, being more easily ignited than polyester, for foam materials, double-sided contact (full wrapping) is more dangerous, and polystyrene foam burns more violently and tends to sustain combustion, posing higher risks than polyurethane foam. The differences in ignition characteristics of different types of combustibles are closely related to their ignition points, thermal conductivity, structural properties, as well as heat accumulation and oxygen supply caused by contact methods.

Keywords: BVV wire, overload, ignition capability, combustible debris, combustible fibers, combustible foam.

1. Introduction

In the investigation of electrical fire accidents, understanding the ignition capacity of copper wires is conducive to accurately determining the cause of fires and distinguishing between fires caused by electrical faults and other factors. Under overload conditions, the temperature of copper wires rises rapidly, which can lead to aging and damage of the wire insulation layer, thereby increasing the risk of igniting surrounding combustibles. In recent years, scholars at home and abroad have conducted systematic studies on the overload ignition characteristics of copper wires to provide theoretical basis for fire safety.

Zheng Shuai et al. proposed that wood shavings can only ignite with open flames when 2.5mm² wires carry more than 100A current and the burial depth is less than 2cm [1]. Lü Xueli conducted experiments on the ignition of combustibles by copper-aluminum wires and concluded that the ignition capacity of overloaded wires is proportional to the overload current and duration, which can ignite directly contacted cotton fabrics and carbonize flame-retardant tubes and waterproof boards [2]. Wei Zhiyu and Cai Guohong explored the ignition capacity of BLV aluminum wires under overload conditions through simulation experiments, providing certain ideas for experimental design [3]. Chen Yilin, Liang Dong, Gao Diance et al. measured wire temperature changes, captured images of the arc generation process, and studied the ignition capacity of BVR copper wires with distances of 0.5cm, 1cm, and 2cm from cotton fabrics. The experimental results showed that the wire overload process is divided into three stages: temperature rise, arcing, and temperature drop. During the arcing stage, arcs are generated at the wire fusing gap and gradually extend to both sides until extinction, causing liquefaction and gasification of the copper core, resulting in molten bead spatter and fluid flame phenomena. High-temperature arcs and molten bead spatter have the ability to ignite surrounding combustibles [4]. Guo Zidong used wires with different cross-sections to ignite combustibles and found that in the absence of combustibles, the parameters of the fitting function have a linear relationship with the overload current multiple, in the presence of combustibles, the relationship is quadratic and cubic polynomials. Additionally, under the same conditions, the final temperature rise of wires with combustibles is higher than that without combustibles [5]. Zhao Yanhong conducted extensive research on the ignition capacity of copper wires under overcurrent conditions, selecting copper wires of different cross-sections to contact cotton fabrics, wood, cardboard, and PVC sleeves respectively. The results showed that the 2.5mm² copper wire has the strongest ignition capacity, and the ignition order of materials is: cotton fabric, wood, cardboard, and PVC sleeve [6].

This study designed experiments and built an experimental platform to investigate the ignition capacity and phenomena of overloaded BVV copper wires on debris materials (paper scraps, wood chips), fiber materials (cotton, polyester), and foam materials (polyurethane foam, polystyrene foam).

2. Experimental Section

2.1 Experimental Materials

A conventional 1.5mm² BVV wire complying with GB/T 19666/JB/T8734.2-2016 was selected as the experimental material. The schematic diagram of the wire cross-section is shown in Figure 1. The wire specifications are as follows: both inner and outer insulation layers are made of polyvinyl chloride (PVC), the thickness of the inner insulation layer is 0.8mm, the outer insulation layer is 1mm, the diameter of the copper core is 1.38mm, and the overall wire diameter is 4.98mm.

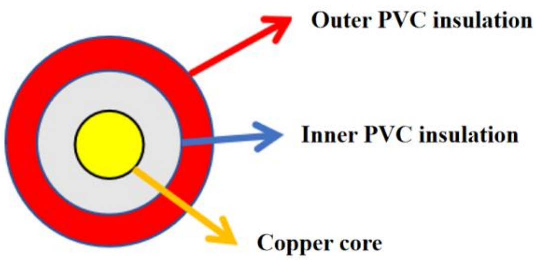


Figure 1. Schematic diagram of the BVV wire cross-section

2.2 Experimental Equipment

Comprehensive experimental platform for fire trace evidence (capable of collecting current and voltage through wires), camera (Nikon Z5 24-50mm kit), high-speed camera, temperature data logger.

2.3 Experimental Process

The device for simulating electrical faults of BVV wires and preparing traces is shown in Figure 2. A 25cm-long BVV wire was cut, and the insulation layer of about 1.5cm at both ends was stripped off. Both ends of the wire were connected to the welding torches in the comprehensive experimental platform for electrical fire evidence. The position of the welding torches was adjusted to keep the wire horizontally laid. A thermocouple was attached to the middle of the wire to measure the surface temperature change of the wire under overcurrent fault. High-speed cameras and ordinary cameras were set up at appropriate positions.

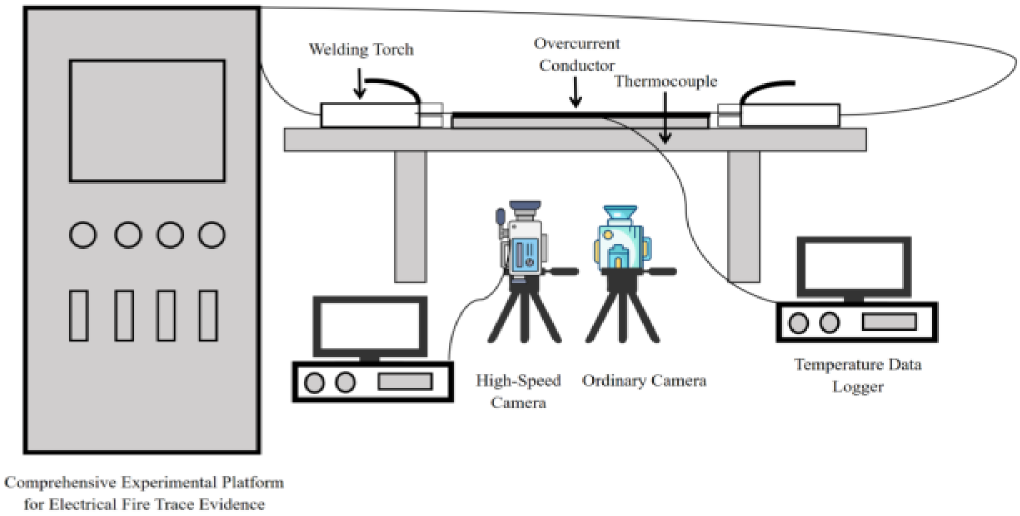


Figure 2. Schematic diagram of the experimental device

The rated current (I_e) of the 1.5mm² BVV copper wire is 18A. The current was gradually increased with I_e as an interval, setting 5 different current values: 4-8I_e (72A, 90A, 108A, 126A, 144A). The surface temperature of the wire was collected by thermocouples, and the heating and change process of the BVV wire under overcurrent fault was recorded by high-speed cameras and ordinary cameras. Each experiment ended when the wire fused or no further changes occurred.

2.4 Experimental Design

(1) Study on the ignition capacity and phenomena of BVV copper wires on debris materials (paper scraps, wood chips) under 6 times the rated current (108A) overload.(2) Study on the ignition capacity and phenomena of BVV copper wires on fiber materials (cotton, polyester) under 6 times the rated current (108A) overload.(3) Study on the ignition capacity and phenomena of BVV copper wires on foam materials (polyurethane foam, polystyrene foam) under 6 times the rated current (108A) overload.

For each study, the materials were contacted with the wire through single-sided contact, full wrapping, half wrapping, and 5mm spacing methods to observe the ignition status and phenomena.

Single-sided contact: The material was laid flat under the 25cm-long wire, with a size of 40cm×25cm to fully cover the wire, simulating the ignition scenario of household cables, charging wires, and electrical equipment wires in contact with curtains, sofas, bed sheets, packaging, file cabinets, etc., as shown in Figure 3.

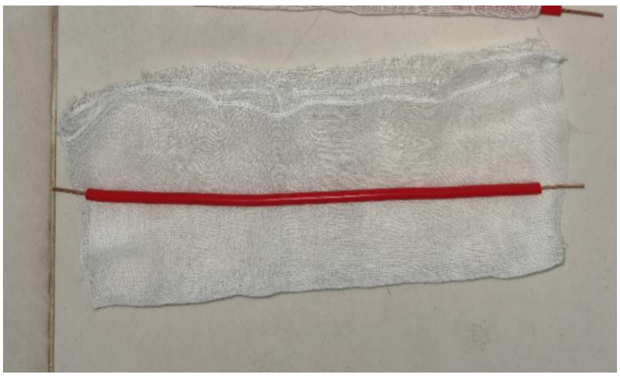


Figure 3. Schematic diagram of single-sided contact

Full wrapping: The 25cm wire was placed in the middle of the 40cm×25cm material, which was folded and aligned to completely wrap the wire, as shown in Figure 4.

Half wrapping: The 25cm wire was placed in the middle of the 40cm×25cm material, which was folded and aligned to wrap half of the wire length (applicable to cotton yarn and polyester), as shown in Figure 4.

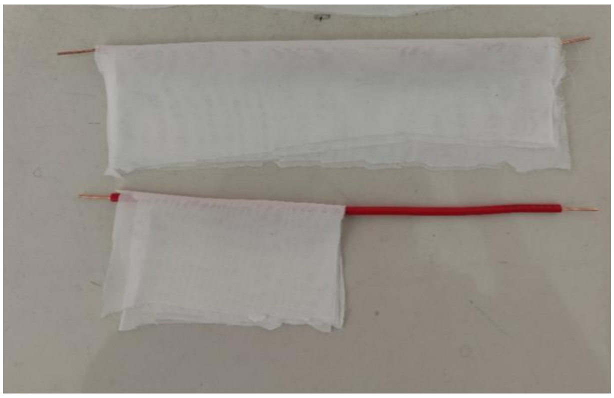


Figure 4. Schematic diagrams of full wrapping and half wrapping

5mm spacing: The wire was placed on the platform with a 5mm gap below to place the material, and the ignition status and phenomena were observed and recorded, as shown in Figure 5.

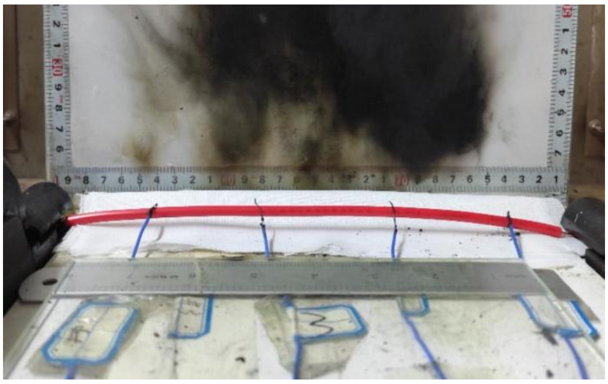


Figure 5. Schematic diagram of 5mm spacing

3. Results and Discussion

3.1 Analysis of Overloaded BVV Copper Wires Igniting Debris Materials

As shown in Table 1, the wire ignited paper scraps with open flames under flat laying and 5mm spacing conditions, while only smoldering occurred when paper scraps were buried 5mm without open flame ignition. In contrast, wood chips were ignited with open flames under all contact methods. In terms of temperature, the temperature of wood chips buried 5mm (545.0℃) was significantly higher than that of paper scraps buried 5mm (274.8℃). The smoke emission times of both materials were similar, ranging from 22 to 28 seconds, with no obvious regular difference, but the smoke emission time was shorter when both were buried 5mm. Regarding ignition time, the ignition time of paper scraps under flat laying was 4s faster than that under 5mm spacing, and no ignition occurred when buried 5mm, the ignition times of wood chips were similar under different contact methods.

Table 1. Macroscopic Phenomenon Parameters of Paper Scraps and Wood Chips Ignition

Material Type	Contact Method	Ignited (Yes/No)	Temperature /℃	Smoke Emission Time/s	Ignition Time/s
Paper scraps	Flat laying	Yes (open flame)	799.0	28.0	57.0
	Buried 5mm	Yes (smoldering)	274.8	23.0	None
	5mm spacing	Yes (open flame)	545.1	28.0	61.0
Wood chips	Flat laying	Yes (open flame)	797.9	27.0	58.0
	Buried 5mm	Yes (open flame)	545.0	22.0	62.0
	5mm spacing	Yes (open flame)	667.4	23.0	62.0

Flat laying Buried 5mm 5mm spacing

(a) Phenomenon of paper scraps 10s after ignition

Flat laying Buried 5mm 5mm spacing

(b) Phenomenon of wood chips 10s after ignition

Figure 6. Phenomena of paper scraps and wood chips 10s after ignition

Comparative analysis shows that the temperature of both paper scraps and wood chips was close to 800°C under flat laying, indicating concentrated heat and easy ignition. The shorter smoke emission time when both materials were buried may be due to faster local temperature rise when the materials are covered. Paper scraps only smoldered when buried 5mm, while wood chips ignited with open flames under the same condition. This is mainly because paper scraps have a lower ignition point and better thermal conductivity, so heat is more likely to diffuse, resulting in a lower temperature, when buried, heat dissipates quickly and oxygen supply is insufficient, leading only to smoldering. In contrast, wood chips have a higher ignition point and poorer thermal conductivity, so heat is more likely to accumulate, resulting in a higher temperature, which is sufficient to sustain combustion even when buried. Under flat laying of paper scraps, the larger contact area leads to higher heat transfer efficiency, so the ignition time is slightly shorter than that under 5mm spacing, however, the ignition time of wood chips has little difference under different contact methods, indicating strong combustion persistence and low sensitivity to contact methods—although it requires a higher temperature for ignition, it is not easy to extinguish once ignited. In summary, wood chips are more hazardous than paper scraps and more easily ignited (as shown in Table 2).

Table 2. Hazard Comparison Parameters of Paper Scraps and Wood Chips

Comparison Parameter	Ignition Point Range/°C	Flame Height	Ignition Time/s	Combustion Mode	Flame Intensity	Toxicity
Paper scraps	218-246°C	Short and dense	57-61s	Smoldering/Open flame ignition	Small	Low
Wood chips	250-300°C	High	58-62s	Open flame ignition	Large/Sustained combustion	High

As can be seen from Figure 6, within 10s after ignition, the ignition area of paper scraps under 5mm spacing was larger than that under flat laying, similarly, wood chips had the largest ignition scale under 5mm spacing, followed by burial and flat laying. It can be concluded that spaced contact poses the highest ignition risk.

3.2 Analysis of Overloaded BVV Copper Wires Igniting Fiber Materials

Table 3. Macroscopic Phenomenon Parameters of Cotton Yarn and Polyester Ignition

Material Type	Contact Method	Ignited (Yes/No)	Temperature/ °C	Smoke Emission Time/s	Ignition Time/s	Firing duration /s
Cotton yarn	Single-sided contact	Yes (open flame)	643.5	26	61	24
	Full wrapping	Yes (open flame)	593.7	27	62	57
	Half wrapping	Yes (open flame)	679.3	25	58	18
	5mm spacing	Yes (open flame)	550.4	28	56	26
Polyester	Single-sided contact	Yes (open flame)	620.5	30	58	35
	Full wrapping	Yes (open flame)	567.3	30	58	37
	Half wrapping	Yes (open flame)	569.5	30	59	40
	5mm spacing	No	432.6	29	Only wire burned	6

Single-sided contact Full wrapping Half wrapping 5mm spacing

(a) Phenomenon of cotton yarn ignition

Single-sided contact Full wrapping Half wrapping 5mm spacing

(b) Phenomenon of polyester ignition

Figure 7. Phenomena of cotton yarn and polyester after ignition

As shown in Table 3, cotton yarn was ignited with open flames under all contact methods, showing low sensitivity to contact methods, with temperatures ranging from 550°C to 700°C. There was no significant difference in smoke emission time and ignition time among groups, the combustion duration was the longest under full wrapping and the shortest under half wrapping. Polyester was ignited with open flames under single-sided contact, full wrapping, and half wrapping, with temperatures also ranging from 550℃ to 700℃ except for the spacing group. However, only the wire burned without igniting polyester under 5mm spacing, with a temperature of 432.3℃. The smoke emission time was similar to the ignition time, but the combustion duration varied significantly—except for the polyester 5mm spacing group, the combustion duration of polyester ranged from 35s to 40s.

Comparing the two materials, cotton yarn is more easily ignited than polyester (as shown in Table 4). The ignition point of cotton yarn is 210–255℃, which is lower than that of polyester (450–485℃). The fluffy fiber structure of cotton yarn facilitates oxygen penetration, and pyrolysis products are easily ignited, thus, the smoke emission time of polyester is longer than that of cotton yarn. Cotton yarn sustained combustion under full wrapping. As can be seen from Figure 7, the flame of ignited cotton yarn was more intense and higher than that of polyester, almost no intact residue of cotton yarn remained, and most of it was carbonized, while polyester was relatively well-preserved—even under 5mm spacing, it was only affected by wire smoke. This phenomenon may be because the porous structure of cotton yarn promotes oxygen penetration, enabling rapid release of a large amount of heat energy and flammable gases, leading to fast flame spread and complete combustion. In contrast, polyester has a dense structure with poor oxygen penetration, it may self-extinguish after melting, reducing flame spread. Comparing the two materials in terms of contact methods, the ignition area was the largest under full wrapping and the smallest under spacing, which is attributed to the difference in contact area.

Table 4. Hazard Comparison Parameters of Cotton Yarn and Polyester

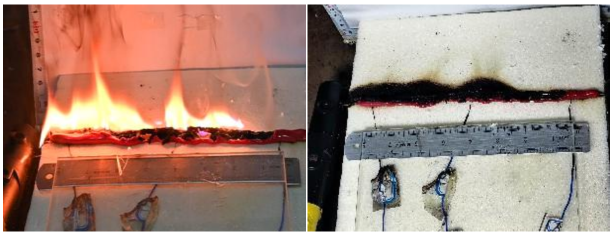
Comparison Parameter	Ignition Point Range/℃	Flame Height	Combustion Duration/s	Combustion Mode	Combustion Scale
Cotton yarn	210-255℃	High	18-57s	Open flame ignition	Large
Polyester	450–485℃	Relatively low	35-40s	Unignited/Open flame ignition	Small

3.3 Analysis of Overloaded BVV Copper Wires Igniting Foam Materials

Table 5. Macroscopic Phenomenon Parameters of Polyurethane Foam and Polystyrene Foam Ignition

Material Type	Contact Method	Temperature /℃	Ignited (Yes/No)	Smoke Emission Time/s	Ignition Time/s	Combustion Duration/s
Polyurethane foam	Single-sided contact	486.0	Yes (open flame)	27	54	23
	Double-sided contact	582.2	smoldering	25	None	None
Polystyrene foam	Single-sided contact	688.3	Yes (open flame)	25	55	9
	Double-sided contact	694.6	Yes (open flame)	26	52	Sustained combustion

As observed in Table 5, the smoke emission time and ignition time of the two foams were similar, but there were significant differences in the maximum wire temperature, flame combustion state, and duration. Polyurethane foam was ignited at a lower temperature with a lower thermal conductivity and pyrolysis temperature, generating flammable gases (such as isocyanate and CO). Under single-sided contact, heat accumulated rapidly locally, with a maximum temperature of 486.0℃, under double-sided contact, uneven internal temperature distribution may occur due to the thermal resistance effect, resulting in more residual char in the foam, which may inhibit open flames and easily cause smoldering. Therefore, open flames only appeared on the single side, and only smoldering occurred under double-sided contact. Additionally, the heat generated by the wire could not dissipate due to being covered on both sides, so the maximum temperature was higher than that under single-sided contact, reaching 582.2℃. Polystyrene foam required a higher temperature for ignition with a higher thermal conductivity, both single-sided and double-sided contacts reached above 650℃, with a slightly higher temperature under double-sided contact. Once ignited, it was prone to sustained combustion (especially under double-sided contact), because its higher pyrolysis temperature generates a large amount of flammable gases such as styrene monomers, leading to intense and sustained combustion, and melting and dripping phenomena exacerbate combustion. Under double-sided contact, polystyrene foam almost completely volatilized, generating open flames. In terms of combustion duration, the duration of polyurethane foam under single-sided contact was longer than that of polystyrene foam, while polystyrene foam sustained combustion under double-sided contact, posing greater hazards.



(a) Single-sided contact of polyurethane foam

(b) Double-sided contact of polyurethane foam

(c) Single-sided contact of polystyrene foam

(d) Double-sided contact of polystyrene foam

Figure 8. Phenomena of polyurethane foam and polystyrene foam after ignition

As can be seen from Figure 8, there was a significant difference in the combustion scale between the two foams. In general, polystyrene foam burned more intensely after ignition with a larger combustion area and greater loss, posing higher hazards (as shown in Table 6). In terms of contact methods, double-sided contact was more hazardous than single-sided contact.

Horizontal comparison: Polyurethane foam has a closed-cell structure with high cell wall strength, which does not rupture rapidly when heated. The carbonized layer generated by pyrolysis is adhesive, which can maintain the overall shape of the foam and prevent collapse. Although open flames occurred under single-sided contact with a duration of 23s, heat was transferred from one side, resulting in a large internal temperature gradient and concentrated combustion area near the heat source. Under double-sided contact, the larger contact area forms a "sandwich structure" with carbonized layers on both sides, making it easier for internal pyrolysis gases to accumulate. The carbon layer is more likely to rupture and become loose at high temperatures, facilitating oxygen penetration into the interior and promoting the spread of smoldering to the interior and surrounding areas of the material [7]. Polystyrene foam was ignited under both contact methods, it sustained combustion until extinguished under double-sided contact, while only burned for 9s under single-sided contact. Notably, during the combustion of polystyrene foam, the foam decomposed and volatilized when heated, forming "cavities". This is because the foam surface rapidly softens and melts at high temperatures, forming liquid polystyrene, leading to the collapse of the material structure, and the unburned internal part forms cavities due to loss of support. Meanwhile, a large amount of styrene monomers and other low-molecular-weight hydrocarbons (such as toluene and ethylene) are generated during pyrolysis, and these gaseous products violently escape from the molten layer, forming bubbles and holes inside the material, which eventually merge into macroscopic cavities. Under single-sided contact, the cavity gradually expands, and there are no combustibles around the wire, so the flame is extinguished. Under double-sided contact, synergistic heating increases the combustible area and promotes more thorough melting, resulting in a cavity penetrating the middle of the material. Sustained combustion maintains high temperature, making the cavity continue to expand and combustion to persist.

4. Conclusions

For debris materials, spaced contact poses the highest ignition risk. Among them, wood chips are more easily ignited than paper scraps, with a larger ignition scale, stronger combustion persistence, and lower sensitivity to contact methods—once ignited, it is not easy to extinguish.

For fiber materials, full wrapping contact poses the highest ignition risk. Among them, cotton yarn is more easily ignited than polyester, with more intense flames and higher height. Cotton yarn is ignited with open flames under all contact methods, showing low sensitivity to contact methods, and almost no intact residue remains (mostly carbonized), polyester is ignited with open flames except for the spacing group, and is relatively well-preserved. Comparing the half-wrapping groups of fiber materials, the comprehensive hazard ranking is: cotton yarn > polyester.

For foam materials, double-sided contact (full wrapping) poses the highest ignition risk. Among them, polystyrene foam is more easily ignited than polyurethane foam, burning more intensely with a larger combustion area and greater loss. Under double-sided contact, penetrating "cavities" are formed, which facilitate flame expansion and pose high hazards.

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