A Systematic Review of Glow Wire Test Performance: Evaluating Polymer Characteristics and Additive Effects on Fire Resistance

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Abstract

In applications where fire safety is of the utmost importance, the Glow-Wire Test is an essential technique for evaluating the fire resistance of polymeric materials. The goal of this systematic review is to compile and evaluate the novel of research on the Glow-Wire Test, with an emphasis on how added materials and polymer properties affect test results. The study thoroughly looks at research on Glow-Wire Test, with a focus on how distinctive polymers behave in tests, how additives or blended polymeric materials affect fire performance, and how different additives affect Glow-Wire Test outcomes. This study aims to provide important insights into the elements influencing polymeric material fire resistance by synthesizing findings from the previous publications. This will help to shape future research directions and improve fire safety standards.

Keywords: Glow-Wire Test, Polymeric Materials, GWFI, GWIT, Flame Retardant

1 Introduction

The discovery of a new plastic in the 19th century, Bakelite created by Leo Baekeland, marked the beginning of the history of the use of plastic and became an important milestone in the history of polymers, where since then, plastic has developed into a material that can offer various beneficial qualities so that it is widely used in society [1]. Engineering thermoplastics such as semi-crystalline aromatic polyester, poly(butylene terephthalate) (PBT), poly(ethylene terephthalate) (PET), polycarbonate bisphenol A, polyamide, polycarbonate (PC), as well as polymer composites are widely used, in the field of electrical electronics, goods white, industrial, and automotive in various forms of application [2-3]. For certain applications, the properties of polymers can be tailored or enhanced through combination with other materials, such as in composites. Polymer materials with their highly flammable nature limit their use in most industrial applications [3]. To prevent possible fire hazards in various applications such as automotive, electrical-electronic, defence, aviation and railway industries etc., thermoplastic polymer materials with fire retardant properties have been used [4].

Polymer materials, especially those used in electrical appliance, basically have the possibility of causing two types of danger: electric shock and fire [5]. As a basis for evaluating fire risk assessment test methods, the evaluation criteria must be clearly stated.

The criteria formulated by Babrauskas and Simonson [5] for electrical equipment emphasize the necessity of designing electrical components to minimize the risk of overheating and fire initiation. Additionally, effective barriers or covers should be implemented to contain any potential fires resulting from electrical faults, preventing them from spreading to external objects. Moreover, if the appliance includes flammable external components, it should be ensured that contact with a small external ignition source does not lead to significant flame propagation.

Kramer and Blomqvist [6] states that there is a general rule (IEC 60947-1) for construction performance requirements stating that: “Parts of insulating material which may be exposed to thermal stress due to electrical influences, and whose damage may compromise the safety of equipment, shall not be adversely affected by abnormal conditions of heat and fire.” To ensure this applies, the standard proposes to use the glow-wire test or hot wire ignition test and, where possible, the arc ignition test [6].

The significance of plastics and their widespread adoption across industries have been highlighted, emphasizing their versatile applications. However, the flammability of engineering thermoplastics and polymer composites poses significant safety risks, particularly in critical sectors such as automotive and electronics. To mitigate these risks, fire-retardant properties have been incorporated into thermoplastic polymer materials. Nonetheless, polymer materials used in electrical appliances present dual hazards of electric shock and fire, necessitating clear evaluation criteria for fire risk assessment methods. Adherence to construction performance requirements outlined in standards like IEC 60947-1 is essential, requiring tests such as the glow-wire and arc ignition tests for equipment safety. Despite these measures, there remains a gap in comprehensive fire risk assessment methodologies for polymer materials in electrical appliances, underscoring the need for further research to enhance safety standards in relevant industries.

Therefore, this paper aims to provide a comprehensive review and deep understanding of evaluating polymer characteristics and additive effects on fire resistance. The remainder of this paper is organized as follows: Chapter 2 introduces the knowledge and understanding of the glow-wire test. In Chapter 3, we elaborate on the characteristic polymers subjected to the glow-wire test. Chapter 4 demonstrates the implementation of knowledge in regulatory considerations and standards compliance, followed by concluding remarks.

2 Glow-Wire Test

The glow-wire test is one of the basic fire tests, which is often used to assess the reaction to fire of materials in electrical equipment [7]. Glow-Wire Test is a basic standard pass/fail test used to assess the suitability of a material for Electrical insulation purposes [8]. The glow-wire test is designed to assess the susceptibility of electrical insulation materials to the risk of ignition of electrotechnical products due to exposure to the glow-wire and ignition if they come into contact with glow-wire due to short circuit [7].

The glow-wire test is based on two tests, namely: GWFI and GWIT. GWFI (Glow-Wire Flammability Index) based on IEC 60695-2-12 [9], which corresponds to the highest test temperature at which the material does not show a flame or glow for more than 30 seconds after the tip of the glow-wire is removed and also does not ignite, through material droplets, tissue paper placed under the test object. GWIT (Glow-Wire Ignition Temperature) is based on IEC 60695-2-13 [10], namely a temperature of 25 °C above the highest temperature tested at which ignition of the material does not occur or does not ignite for more than 5 seconds in three consecutive measurements. Meanwhile, glow-wire test equipment and other general test procedures are described in IEC 60695-2-10 [11].

Based on IEC 60695-2-10 [11], in glow-wire testing, the wire used is nickel/chromium-based (80/20) 4 mm thick, bent to a radius of 1 cm, heated to a certain temperature in the range of 650 °C to 960 °C. The front surface of the specimen is pressed by a glow-wire with a small force of

1±0.2 N. The glow-wire is applied for 30 seconds at the same current supply without compensating for a decrease or increase in temperature at the end of the glow-wire. The tip of the glow-wire is allowed to penetrate the sample to a maximum depth of 7±0.5 mm from the front surface of the specimen. The start-up time and shutdown time are recorded. The tissue paper indicator is placed 200 mm below the glow-wire and it is noted whether the droplets of flaming material ignite the tissue paper indicator or not.

3 Characteristic Polymer Subjected to Glow-Wire Test

The glow-wire technique evaluates the flammability properties of polymer materials used in electrical components [12]. Each polymer material has different material properties so that its flammability behaviour also varies. Polymer materials in everyday life are usually added with other supporting substances to improve the material properties according to their needs. Several types of polymers such as PP [7, 12-16], PBT [2,8,17], EBA30 (poly[ethylene (30%)-butyl acrylate] copolymer) [18], PET [2,8], PC [2,6,8], Polyamide [6,8,19-21], HDPE (High-density polyethylene) [6], EPDM (Ethylene-propylene-diene monomer) [22], nylon [23], ABS (Acrylonitrile-Butadiene-Styrene) [1,3,6], PLA (poly(lactic) acid) [24]. It is not uncommon for polymer materials to be combined with other materials such as natural fibre and synthetic materials to become composite materials that have the desired material properties.

3.1 Additive/Blended Polymeric Material

Additional substances added to polymers are generally intended to strengthen the material properties of the polymer itself, from strengthening its mechanical properties (density, strength, hardness, ductility, stiffness etc.) to strengthening its fire resistance properties. Fire resistance means that the material, when exposed to a flame, is able to inhibit the growth and propagation of the flame or simply prevent ignition. The most common way to prevent polymers from burning is to use flame retardants, where flame retardants refer to additives that help a material, especially polymers, to slow down the flame [25]. Flame retardant (FR) additives may not burn forever, but they are more difficult to burn and can often self-extinguish.

There are many types of flame retardant (FR) materials commonly used in polymers, from synthetic chemicals to organic materials. In its application, fire retardant additives can be added by mixing them with polymer compounds and then forming them using several material manufacturing processes such as extrusion/extrusion moulding, injection moulding, roll mill etc. Table 1 shows the flame retardant additives commonly added to polymers to increase their flame retardant properties.

Table 1. Flame retardant additive material

Flame Retardant Material	Literature Source	Blending Method
Aluminium diethyl-phosphinate (AlPi)	[3, 8, 19, 21]	Extrusion (twin screw extruder)
Zeolite	[12]	
Sillicate	[12]	
Cloisite	[18]	
Magnesium dihydroxide (MDH)	[20]	
Melamine polyphosphate (MPP)	[8, 19]	
Polystyrene brominated (BrPS)	[8]	
Mica mineral	[14]	
Piperazine-pyrophosphate (FP)	[22]	Two roll mills (for rubber)
Polyaniline (PANI)		
Macroalgae	[24]	Injection moulding
Decabromodiphenyl ethane (DBDPE)	[23]	Injection moulding and extrusion moulding
Ammonium polyphosphate (APP)	[3, 13, 14, 16, 18, 22]	Extrusion (twin screw extruder), two roll mill (for rubber), injection moulding, pressure moulding
Nitrogen/silicon-based macromolecules (MNSi)	[16]	
Melamine cyanurate (MCA)		
Pentaerythritol (PER)	[3,18, 22]	
Glass-fibre	[2, 8, 17, 20, 21, 23]	Extrusion (twin screw extruder), injection moulding

3.2 Additive Material Influence on Glow-Wire Test Result

The addition of flame retardant material to polymer materials has a significant impact on the fire resistance of the polymer material. Table 2 presents the data series of the GWFI and GWIT results of several polymer materials with additional FR material. Not all of them display complete GWFI and GWIT data results. Based on table 2, pure polymer materials, such as PP, EBA30, EPDM, and PLA, are sufficient to pass the glow-wire test criteria with a GWFI above 650 °C without the addition of FR. As seen from Table 2, only ABS [3] fails to meet the GWFI criteria and the material with pure polymer (without FR) with the lowest GFWI is PP [12] with a value of 650/7.0.

Table 2. The data series of glow-wire test results on polymer materials

Base Polymer Material	Source	Additive Flame Retardant	GWFI	GWIT
PP	[6]	Unspecified (metal hydroxide)	800/1.5 850/3.0	825/1.5 850/3.0
	[12]	Pure/no FR	650/7.0	700/7.0
		Zeolite	960/7.0	875/7.0
		Silicate	960/7.0	850/7.0
	[13]	Pure/no FR	-	725/3.0
		Kenaf + wool + APP	-	800/3.0
	[14]	IFR + mica mineral	750/-	850/-
	[16]	Pure/no FR	725/3.0	750/3.0
		MCA/APP	825/3.0	775/3.0
		MNSi/APP	960/3.0	850/3.0
PBT	[2,8]	Glass-fibre	-	750/3.0 725/1.0
	[8]	Glass-fibre + BrPS	-	675/3.0 650/1.0
		Glass-fibre + AlPi	-	750/3.0 725/1.0
		Glass-fibre + MPP	-	750/3.0

				675/1.0
EBA30	[18]	Pure/no FR	750/3.0	750/3.0
		Cloisite	800/3.0	750/3.0
PET	[2,8]	Glass-fibre	-	675/3.0 700/1.0
PC	[2,8]	Glass-fibre	-	825/3.0 825/1.0
	[6]	not known	960/1.5 960/3.0	750/1.5 725/3.0
Polyamide	[8]	Glass-fibre	-	675/3.0 675/1.0
	[6]	Unspecified (non-halogen FR)	960/1.5 960/3.0	875/1.5 875/3.0
	[19]	AlPi + Glass-fibre + MPP	960/1.2	700/1.2
	[20]	Glass-fibre	650/1.2	700/1.2
		Glass-fibre + MDH (H5A)	960/1.2	700/1.2
	[21]	AlPi + Glass-fibre	850/1.0	-
		AlPi + Glass-fibre + Intumescent coating	960/1.0	-
HDPE	[6]	Unspecified (metal hydroxide)	850/1.5 960/3.0	800/1.5 850/3.0
EPDM	[22]	Pure/no FR	775/3.0	700/3.0
		APP	900/3.0	700/3.0
		PER	750/3.0	700/3.0
		PANI	800/3.0	750/3.0
		FP	750/3.0	725/3.0
Nylon	[23]	DBDPE + glass fibre	775/0.75	-
ABS	[3]	Pure/no FR	failed	-

		AlPi + APP	960/2.5	-
		AlPi + APP + PER	960/2.5	-
	[6]	Unspecified (phosphorus)	960/1.5 960/3.0	875/1.5 875/3.0
PLA	[24]	Neat/no FR	825/2.0	-
		Macroalgae	775/2.0	-

Based on Table 2, glass-fibre is often mixed as an additive substance in polymer materials. It is not yet known for certain whether glass-fibre, apart from increasing the mechanical strength of polymers, can also function as FR. Overall, FR materials have a good effect on the fire resistance of polymer materials. But not all can reach the maximum test temperature of 960 °C. FR materials such as AlPi (Aluminium diethyl-phosphinate), APP (Ammonium polyphosphate), and PER (Pentaerythritol) are quite often used. From the data series in Table 2, only polymer types PP [12,16], PC [6], polyamide [6,19,21], and ABS [3,6] can have a maximum value of GWFI: 960/"thickness".

As an illustration, the following is documentation of the glow-wire testing process carried out by Acquasanta et al. [8] and Casetta et al. [20] shown in Fig. 1. It can be seen that the specimen in fig. 1(a) has a very large flame and looks difficult to extinguish when it came into contact with the glow-wire. In Fig. 1(b) the burning specimen material is caught in the glow-wire and is still ignited even though the glow-wire has been removed.

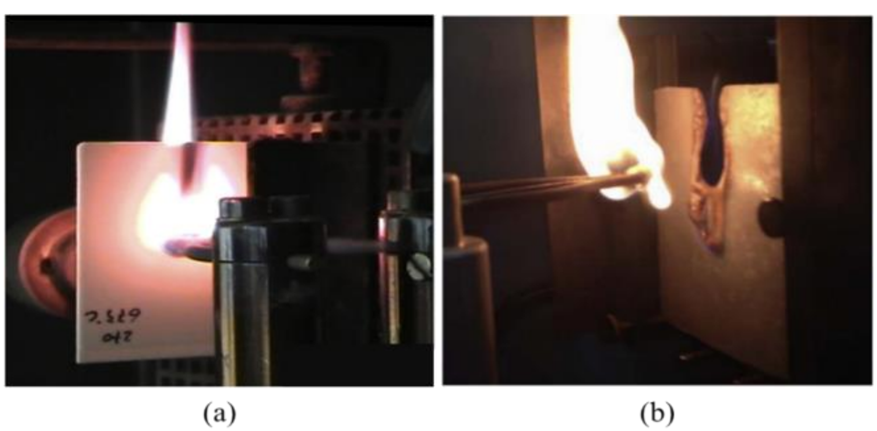

Fig. 1. The glow-wire testing process on polymeric specimen carried out by (a) Acquasanta et al. [8] and (b) Casetta et al. [12].

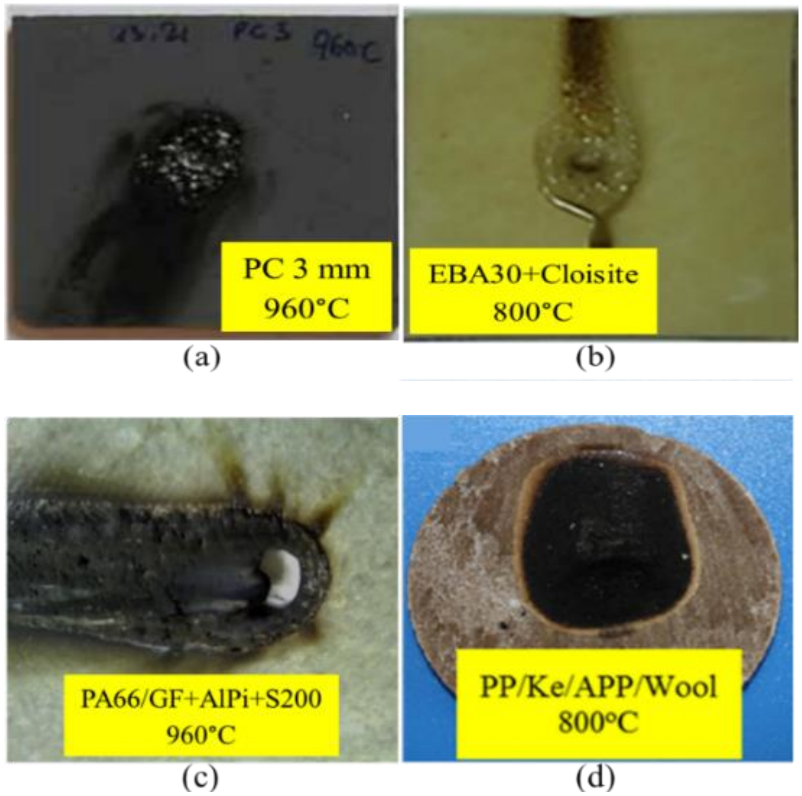

Fig. 2. The result of glow-wire penetration into several polymer materials, (a) PC [6], (b) EBA30 [18], (c) Polyamide 66 (PA66) [19], and (d) PP [13].

Fig. 2 shows the final results of the glow-wire test on several polymer materials. The results shown differ depending on the composition of the material used. All specimens shown in Fig. 2 successfully met glow-wire testing standards and did not produce flaming droplets. However still, all specimens have small-scale intumescence or burning areas that expand around the wire contact point which makes it characteristic of the material resulting from the glow-wire test. The PA66 material appears to have holes even though it reaches a GWFI temperature of 960 °C, while the other materials, PC, EBA30, and PP, only appear to have small depressions. Material penetration is also an important factor in this case to protect the underlying material from burning.

4 Regulatory considerations and standards compliance

Regulations regarding matters relating to glow-wire tests have been explained by the International Electrotechnical Commission (IEC) [9-11]. Observation of glow-wire test results has its own criteria depending on the standard to be achieved, GWFI or GWIT. Based on the data series of glow-wire test results on polymer materials from Table 2, there was an error in stating the GWFI and GWIT values in one of the tests that used PP base material with FR in the form of IFR and mica minerals [14]. The error occurred due to lack of information about specimen dimensions, especially the thickness of the test specimen, it is not listed. Based on IEC 60695-2-12 [9] concerning GWFI and IEC 60695-2-13 [10] concerning GWIT, reporting of GWFI and GWIT results must refer to:

a. Test result temperature and specimen thickness, with writing examples as follows: GWIT: 850/3.0; GWFI: 850/3.0,
b. In cases where the material under test does not ignite during the test, the GWFI test procedure does not need to be performed. The GWFI for this material is 960 °C at the relevant thickness,
c. In case the test does not result in ignition using a test temperature of 960 ºC, the GWIT should be reported as follows: GWIT: >960/"thickness",
d. Representative GWFI and/or GWIT for various thicknesses should be reported in the following manner: GWFI: 850/0.75-3.0; GWIT: 775/0.75-3.0.

5 Conclusions

This paper has reviewed the glow-wire test performance providing a general background and a literature survey about evaluating polymer characteristics and additive effects on fire resistance. It has been a comprehensive review since it has considered the main idea introduces the knowledge and understanding of the glow-wire test, the characteristic polymers subjected to the glow-wire test, and the regulatory considerations and standards compliance. As shown in the present paper, the glow-wire testing method assesses a plastic propensity to resist ignition when subjected to overloaded wires, and monitors its ability to self-extinguish without spreading to other areas or components within the appliance. Therefore, it is anticipated that this paper will serve as a valuable reference for future investigations in the field of fire resistance testing and polymer materials.

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