

# Development of TEX-B Solderable, Heat-Resistant, Triple-Insulated Winding Wire

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**ABSTRACT** Furukawa Electric's TEX-E general-purpose triple-insulated winding wire has come into wide use due to the trend toward decreasing the size and cost of switching power supply transformers, and to the fact that transformers are easier to recycle. It also makes possible the design of transformers that are environment-friendly. It is expected, however, that the trend in power supply units toward downsizing and higher efficiency will continue, and this will raise problems with respect to heat generated by the component parts and the effects of heat dissipation due to smaller size and higher mounting densities. It is essential that the materials used be of higher heat resistance.

To meet these needs we have developed TEX-B solderable, heat-resistant (Class B), triple-insulated winding wire. Among the technologies employed were those of polymer alloying, polymer evaluation, and thin coating. Approvals have been obtained from certification authorities world wide with respect to important safety standards relating to switching power supply transformers. This report describes the development of TEX-B wire, together with its characteristics.

## 1. INTRODUCTION

In recent years there have been advances in downsizing electronic and electrical equipment, presenting various needs with respect to power supply units--namely smaller size, lighter weight, higher efficiency, lower noise levels and lower cost. The mainstream means used in the downsizing of power supply units is known as the switching power supply, which is a type of DC stabilized power supply controlled by the switching method. Input from commercial-frequency AC power supply or DC power supply is converted into power of a frequency above the audio frequencies and then controlled and rectified to provide the desired DC output. The conversion into high-frequency power is accomplished by high-speed switching of semiconductors. In a power supply unit of this type, increasing the switching frequency allows a reduction in the number of transformer windings, resulting in a smaller unit. When it is desired to have an even slimmer unit or attain higher-density mounting, materials of higher heat resistance must be used, since heat generation from the component parts and poorer heat dissipation will cause problems.

We have accordingly developed the TEX-B solderable, heat-resistant, triple-insulated winding wire, which meets these requirements. Each of the three layers of insulation over the conductor of the TEX-B winding wire is approxi-

mately 33  $\mu\text{m}$  thick, or about 100  $\mu\text{m}$  in total. In response to the requirements of the safety standards, any two of the insulation layers can withstand a voltage of 3000  $V_{\text{rms}}$  for 1 min. TEX-B also has Class B heat resistance, and features better electrical endurance and a higher voltage for the inception of partial discharge. This report describes the development of TEX-B wire, together with its characteristics.

## 2. SAFETY STANDARDS AND THE ROLE OF TRIPLE-INSULATED WIRE

There are two important safety standards for final products that use switching power supplies: IEC 60065 "Safety Requirements for Mains Operated Electronic and Related Apparatus for Household and Similar General Use" and IEC 60950 "Safety of Information Technology Equipment" issued by the International Electrotechnical Commission.

The primary aspects of safety requirements for transformers are the insulating characteristics between the primary and secondary coils, and the provision of creepage distance. When enameled wire is used (an enamel film is not recognized as an insulator), an interleaving tape or barrier must be interposed between the primary or secondary coils. When Furukawa Electric's triple-insulated wire is used, on the other hand, the insulation layer fulfills that role so there is no need for interleaving tape or a barrier, simplifying the structure and reducing the size of the transformer.

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### 3. DEVELOPMENT OF TEX-B

When it is desired to achieve an even thinner profile, higher efficiency and greater mounting density, a material with higher heat resistance is required. This is because of the problem posed by heat generated from the component parts and a deterioration of heat dissipation performance. An investigation was therefore conducted drawing on the technologies of polymer alloying, polymer evaluation, and thin coating.

#### 3.1 Polymer Alloying Technology

The basic requirement for any polymer to be used in transformers is that it possess the various characteristics required for winding wire. Of these the primary objective was Class B heat resistance, and solderability and resistance to chemical attack were also identified as important.

It is difficult for a winding wire to achieve both Class B heat resistance and solderability. Let us consider one of the mechanisms of solderability. When the triple-insulated wire is dipped in the solder melt the insulation either melts or decomposes from the heat. The solder then instantly enters into the space between the insulation layer and the conductor, the conductor is wetted with solder and in a

short time the solder adheres to the conductor.

On the other hand the insulation layer must be sufficiently heat resistant. It is essential that the heat of the solder not melt or decomposes the insulation too easily, and we have accordingly investigated the relationship between heat resistance and solderability for heat-resistant thermoplastic resins. As a result, it was found that all resins having good solderability were lower in heat resistance than Class B (see Figure 1).

It was here that the techniques of polymer alloying were employed to combine resins with the mutually exclusive properties of heat resistance and solderability to produce a resin that has both. A variety of resins were combined and the proportions optimized until a specially modified polyethersulfone resin was found that satisfied the requirements. It has a morphology in which a resin having the property of solderability forms a fine dispersion evenly through a heat-resistant matrix resin (Photo 1).

A number of heat-resistant thermoplastic resins were considered for use as a resin resistant to heat and chemical attack, and from among them we selected polyphenylenesulfide which is capable of high-speed thin coating. It was decided that the basic structure of TEX-B heat-resistant triple-insulated winding wire would be a 1st and 2nd layer of modified polyethersulfone and a 3rd layer of polyphenylenesulfide.

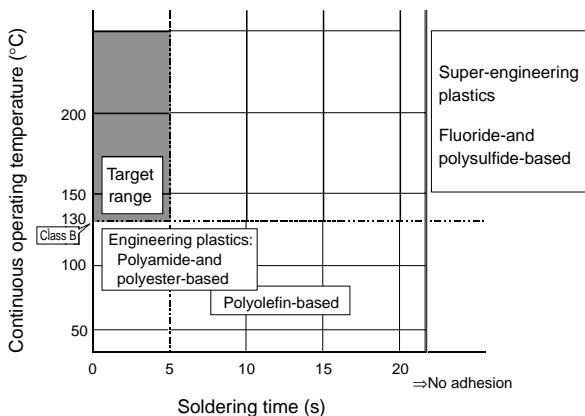


Figure 1 Solderability of engineering plastics.

#### 3.2 Thin Coating Technology

Thin coating technology is used in TEX-E general-purpose triple-insulated winding wire, and was also adopted in developing TEX-B. High-speed thin coating of resin with high heat resistance and thermoplasticity requires that the resin have a suitable melt viscosity and the melt tensile strength required for high-speed coating. The coating characteristics of a resin can be found by establishing the melt viscosity of the resin and its viscosity behavior when melted. The process involved repeated comparisons of actual coating characteristics and optimization of coating conditions.

### 4. TEX-B CHARACTERISTICS

In this section we will discuss the properties of TEX-B, including the basic characteristics of winding wire plus electrical properties and solderability. The electrical properties deserve particular attention.

#### 4.1 General Characteristics

The main characteristics of TEX-B are shown in Table 1, and compared with those of TEX-E general-purpose triple-insulated winding wire which has Class E heat resistance. It can be confirmed that in each of the characteristics there is virtually no difference between the two. It was also confirmed that, of the safety standards relating to switching power supplies, the conditions for Class B are satisfied with respect to Annex U and Modified Annex C of IEC 60950. The surface hardness of the TEX-B insulation layer, however, was lower than that of enameled wire. Full

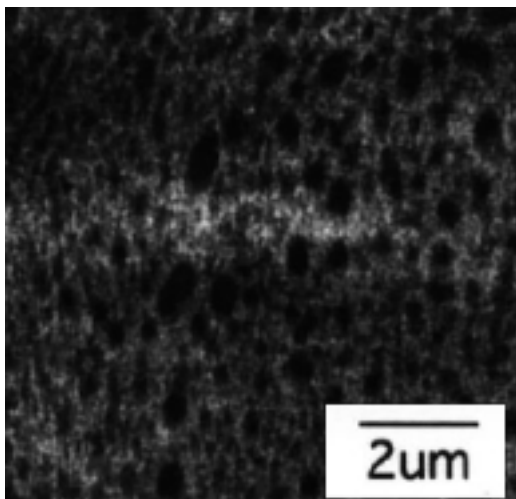
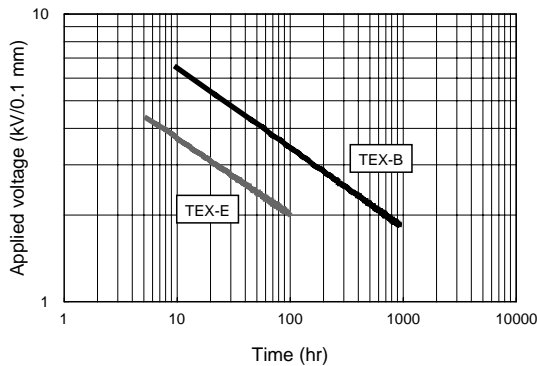


Photo 1 Morphology of modified polyethersulfone (by SEM).

**Table 1 Comparison of Characteristics of TEX-B and TEX-E.**

Characteristics		TEX-B	TEX-E
Dimensions	Conductor diameter (mm)	0.400	0.400
	Overall diameter (mm)	0.600	0.600
	Insulation thickness (mm)	0.100	0.100
Dielectric breakdown Voltage (kV)		26.0	23.4
Solderability [420°C] (sec)		< 10	3.0
Solderability [450°C] (sec)		5.0	—
Heat shock [150°C X1 hr]		1D	1D
Cut-through (°C)		245	231
Unidirectional abrasion (N)		21.57	19.31
Reciprocated abrasion (times)		260	285
Static friction coefficient		0.11	0.085
Adherence (mm)		4.0	< 0.5
Chemical resistance	Xylene	4H	3H
	Styrene	3H	3H
IEC 60950	Annex U.2.1	Pass	Pass
	Annex U.2.2	Pass	Pass
	Annex U.2.3 [Class E]	Pass	Pass
	Annex U.2.3 [Class B]	Pass	—
	Annex U.2.4	Pass	Pass
	Modified Annex C [Class E]	Pass	Pass
	Modified Annex C [Class B]	Pass	—

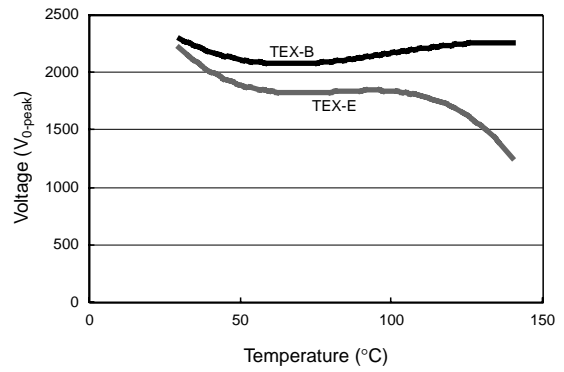


**Figure 2 Comparison between V-t characteristic of TEX-B and TEX-E at 50 Hz.**

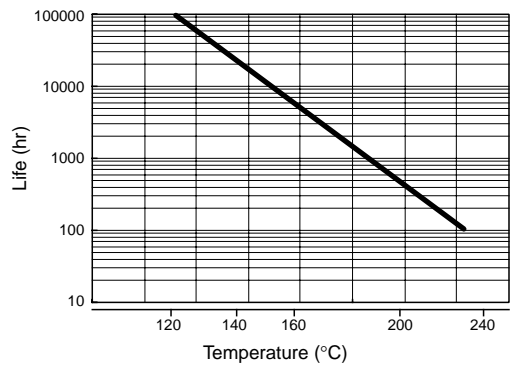
attention must be paid to tension during winding. On the other hand TEX-B is solderable, but requires a slightly higher solder melt temperature than TEX-E.

#### 4.2 V-t Characteristic

Figure 2 shows the results of measurement of V-t characteristics at room temperature for commercial-frequency (50 Hz) AC. The lifetime is considerable longer for TEX-B than for general-purpose TEX-E. It was confirmed that electrical endurance is improved, and this is attributed to the improved heat resistance of the insulation layers of which TEX-B is made, so that it was able to withstand the heat generated when the voltage was applied.



**Figure 3 Comparison between partial discharge inception voltages of TEX-B and TEX-E at 10 kHz.**



**Figure 4 Temperature index for TEX-B.**

#### 4.3 Temperature Dependence of Partial Discharge Inception Voltage

Figure 3 shows the results of measurements of the temperature dependence of the partial discharge inception voltage with a straight-polarity rectangular wave of 10 kHz, a pulse width of 10  $\mu$ s and a detection sensitivity of 10 pC. For TEX-B wire the rated temperature is 130°C, but even at 140°C the same level of partial discharge inception voltage was maintained as for room temperature, whereas for the general-purpose TEX-E wire there was a tendency for the voltage to decrease as temperature rose. One reason for this superiority of TEX-B over TEX-E is thought to be the higher glass transformation temperature  $T_g$  of the resins used in the insulation layers of TEX-B.

#### 4.4 Thermal Endurance Characteristic

The thermal endurance characteristic was investigated in conformance to the standard for establishing the temperature index for enameled wire (IEC 60172), and Figure 4 shows the results obtained. It was confirmed by an Arrhenius plot that a temperature index corresponding to a life of 20,000 hours satisfies the level of Class B heat resistance.



Photo 2 TEX-B wire after soldering.

#### 4.5 Solderability

A 40-mm length of TEX-B wire was immersed in a solder melt and the length to which solder adhered was measured. It was found that at 450°C solder adhered over 30 mm or more within 5 sec (Table 1), a result that was somewhat inferior to that of TEX-E wire. Solderability was then confirmed for TEX-B when wound onto phenol resin bobbin material. Observation of the adherence of solder to the bobbin showed virtually no damage with respect to the TEX-B wire, confirming the feasibility of highly reliable soldering (Photo 2).

### 5. OBTAINING SAFETY CERTIFICATION

TEX-B wire has received approval from certification bodies in several countries as complying with safety standards for switching power supplies (Table 2). Approvals were received in October 2001 from CSA (Canada), and from NEMKO (Norway) in November, from UL (USA) in December, from VDE (Germany) in January 2002, and from BSI (UK) in March.

Table 2 Safety codes certifying TEX-B wire.

Test-house	Country	Safety Code
CSA	Canada	CAN/CSA-C22.2 No.1-98
		CSA Std C22.2 No.66-1988
		CAN/CSA-C22.2 No.223-M91
		No.234-M90
		No.60950-00
		CAN/CSA-E60065-00
NEMKO	Norway	IEC60950 3 <sup>rd</sup>
		IEC60950/FDIS 4 <sup>th</sup> Ed
		IEC60065/FDIS 7 <sup>th</sup> Ed
UL	USA	UL1950 (OBJT2)
VDE	Germany	DIN EN 60950 (VDE 0805):2001-12
		EN 60950:2000
		IEC 60950:1999+corr.2000 modif.
		DIN EN 60065:1998 (VDE 0860:1999-10)
BSI	UK	BS EN60065:1998
		IEC 60065 6 <sup>th</sup> Ed:1998
		BS EN 60950:2000

### 6. CONCLUSION

We have developed TEX-B solderable, heat-resistant (Class B), triple-insulated winding wire. TEX-B wire has received approval under important safety standards relating to switching power supplies from certification authorities in several nations. It is proposed that UL1446 (Systems of Insulation Material - General) will be obtained for insulation systems including bobbin materials.

In terms of trends in switching power supply technologies, investigations are being actively carried out on achieving slimmer profiles and higher efficiency, as well as greater mounting density. It is anticipated that Furukawa Electric's triple-insulated winding wire will play a role in a widening range of fields.