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Review
Recent research in carbon plastic composites in the former Soviet Union

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Research in carbon plastic composites in the former Soviet Union is reviewed for the period 1982–1992. There is a significant volume of research. Carbon fibres with tensile strengths greater than 5 GPa are being produced. Composites have inferior properties to the most advanced Western materials, tensile strengths being about 35% lower. The most significant research effort is in fibre/matrix interface studies. Activated and chemically modified carbon fibres have been extensively studied and the scope of this work is sometimes in advance of the West.

1. Introduction
The terms Soviet Union, Soviet or USSR used in this paper refer to all the states of the former Soviet Union. There is a large volume of Soviet academic research in the field of carbon fibre reinforced materials. Since 1990 some information has also become available from production organisations.

Citations in Chemical Abstracts for the period 1982–1992 about research in carbon fibres show 643 from the USSR, 1436 from the USA and 4990 from Japan. From this it is clear that Japan clearly leads this field in terms of the volume of published research, but there could be a broadly comparable volume of research in both the USA and the USSR given that the opportunities to publish in the Soviet Union are significantly less than in the USA, because of security restrictions and the smaller number of journals in the field.

The number of publications is of course only a very approximate guide to research capability. It is significant that the Soviet publications concentrate on fundamental and theoretical work. In the area of fibre treatment specifically done to improve carbon polymer composite properties, which is a critical area of research, a significant number of Soviet citations were found for the period reviewed. The general area of fibre modification and treatment is also very strongly represented in the Soviet literature and in some respects research is more advanced than in the West.

This strong research base is not, however, reflected in the quality of the final product, i.e. the composite material.

2. Carbon fibre properties
Carbon fibres are routinely produced in the USSR from viscose fibres and from PAN. Production of the viscose type in the West has been largely phased out because of complicated production methods and inferior mechanical properties. The production of pitch-based fibres is only just starting in the USSR, with the first factory beginning operation in the early '90s [1].

Table I shows the available brands of viscose-based carbon fibres in the Soviet Union. If a nominal value of density is assumed of 2000 kg m^{-3}, the maximum specific strength in the table, of Ural LO-22, is 10×10^4 m. It has been claimed that a viscose fibre with an elastic modulus of 700 GPa and tensile strength of 3 GPa has been produced [1]. Fibres produced in research laboratories, based on viscose do not have properties significantly different from those quoted above [2, 3].

Table II shows the properties of 15 production grades of PAN fibres. Table II shows that high modulus, high strength and ultra-high modulus fibre grades are relatively common, but there is little evidence of ultra high strength fibres with a specific tensile strength of more than 32×10^4 m, corresponding to a tensile strength of about 5 GPa. This has been attributed to difficulties in producing efficient production technology for tows and tapes [1]. A very recent publication has, however, reported a new grade of fibre, UKN-P/5000-0.1 with a tensile strength of 6.0 GPa [5]. The first ultra high strength fibre was reported very recently. Production techniques generally lag behind the West. The pyrolysis of cellulosic material is still a widely employed method to make carbon fibres, although it has been largely superceded in the West; and pitch-based fibres are still at an early stage of development. New techniques, such as pyrolytic deposition of hydrocarbons from the gas phase, have not been reported, even though this particular method was first studied in Japan in 1976 [6] and carbon fibres from pitch were first produced in the laboratory in 1965 [7], also in Japan.

TABLE I Soviet carbon fibres based on viscose [1]

Material designation	Form of material	Ultimate tensile strength of filament (GPa)
Ural T-22	Fabric or tape	1.3
Ural Tr 3/2-15	Tricotage	1.0
Ural TM/4-22	Fabric	1.3
Ural LO-22	Tape	2.0
Ural N	Yarn	1.5
UUT-2	Fabric	0.8
UTM-8	Fabric	0.6
Uglen	Tow	0.5

TABLE II Properties of Soviet carbon fibres based on PAN precursor [1, 4, 5]

Material designation	Form of material	Specific tensile strength (m × 10^4)	Specific modulus (m × 10^6)
LL-P-0.1 and 0.2	Tape	18.0	16.2
ELUR-P-0.1 and 0.08	Tape	19.2	15.0
UKN-P 5000 and 2500	Tow	20.4	13.4
UKN-P 500M	Tow	26.2	14.0
KULON	Tape	13.0	26.1
KULON-M	Tow	15.7	31.4
UKN 400	Tow	27.0	15.0
GRANIT-P	Tow	23.0	23.0
KULON	Tow	18.3	28.8
LU-P	Tape	17.5	16.3
LU-24P	Tape	17.2	20.8
KULON-P	Tape	15.7	28.8
UKN-P 5000-0.1	Tow	34.8	N/A
GRANIT 35P	Tow	23.2	N/A
KULON-H 24P	Tow	21.1	N/A

N/A, not available.

3. Prepregs and Preforms

Relatively little information is available on prepregs and preforms. It is typical of the Soviet system that details of applied science and technologies are harder to find than information on fundamental research.

In one case the values of the Glass Transition Temperature, T_g, are given for a series of epoxy resins used in the experiment. All were greater than 110 °C [8]. Of the remaining references, information is not available on T_g or the filler material, although in two cases a novalak epoxy binder is used, which can have a high T_g [9, 10].

There are 3 references to prepregs based on thermoplastic binders, all from the same research group [11–13]. The binders used included PEEK and polyamideimide.

It is not possible to reach a firm conclusion about the general technological level of prepreg production due to the lack of information. There is only one mention of using a hot melt impregnation method and this was in one of the most recently published reports [12]. This could indicate a lag developing this area, which attracts considerable interest in the West. No references were found about carbon fibre preforms.

4. Carbon fibre-polymer matrix composites

There is a significant body of publications under this heading, covering composite properties, including fibre treatment to improve properties, and theoretical analyses of the mechanics of carbon plastics. Text books and data books have also been published [14, 15].

A comparison of production grades of epoxy–carbon composites with Western proprietary materials of a similar composition showed that the Soviet composites had inferior properties. Modulus and tensile strength were both about 20% lower [14]. This was based on data available in 1988. More recent information is presented in Table III.

Materials 1–8 in Table III are production grades of composite, 9–13 were developed in the laboratory. The carbon plastic composites shown in Table III were selected to represent the most advanced about which information is available. They have properties which are similar to some production grades of composites in the West, but fall below the strength of the most advanced materials by about 35%.

A review of research shows that there is relatively little work on high performance thermoplastic matrix composites [11–13, 16, 21–40]. The materials produced do however have properties comparable to some Western composites (Table III). The majority of research is done on thermosetting epoxy resins. In

TABLE III Properties of various Soviet carbon–plastic composites [16–20]

Carbon fibre type	Matrix material	Tensile strength (GPa)	Compressive strength (GPa)	Modulus (GPa)
1 UKN-P 5000 and 2500	Polymer	1.2–1.5	1.0–1.2	120–140
2 UKN-400	Polymer	1.8–2.0	1.2–1.4	130–150
3 GRANIT-P	Polymer	1.2–1.5	0.9–1.2	180–220
4 KULON-P, Tow	Polymer	1.0–1.3	0.6–0.8	250–300
5 ELUR-P	Polymer	0.9–1.1	0.9–1.1	120–140
6 LU-P	Polymer	0.7–0.9	0.7–0.9	130–180
7 LU-24P	Polymer	1.2–1.3	0.9–1.0	235–250
8 KULON-P-Tape	Polymer	0.9–1.1	0.65–0.85	250–280
9 ELUR-P	Polyamide–imide	1.1	N/A	127
10 UKN-P	Bismaleimide	1.8	1.1	N/A
11 UKN-P	Aromatic polyimide	1.8	1.2	N/A
12 Carbon tow	Polysulfone	1.4	N/A	128
13 Carbon fibre	Phenolic resin	1.2	N/A	248

N/A, not available.

this area there is a significant interest in improving damage tolerance and hot/wet performance, although research is not on the same scale as in the West. Promising processing techniques such as resin transfer moulding have not been reported, although pultrusion is used. Major attempts do not appear to have been made to improve the processability of matrices for economic reasons. A large research effort has been put into developing carbon plastics as friction materials, including using fluoropolymers.

By far the most significant Soviet effort in carbon plastics is in fibre/matrix interface studies. Wet and dry oxidative treatments have been widely studied. Improvements in adhesion, as measured by interlaminar shear strength have been reported. Other treatments to improve wettability have been tried, such as neutron bombardment [17–20, 41, 42]. Activated and chemically modified carbon fibres have been extensively researched [43–49]. These techniques can significantly improve adhesion. A Western review of Soviet work on chemically modified carbon fibres was published recently [50]. The scope of the research is wide and sometimes is in advance of the West. The main interest in this field is in improving the properties of composites based on low and medium modulus fibres. There is a great commercial incentive to do this, but so far the impressive Soviet effort in basic modified fibre research has not been fully applied to improving composite properties.

There is a large amount of literature devoted to the mechanics of carbon plastics. Methods of analysis are usually based on classical theories. There are relatively few papers on fracture mechanics and numerical methods are rarely used.

5. Conclusion

Carbon fibre organic matrix composites have been the subject of a large Soviet research effort. The most recently available information shows that high performance composites have tensile strengths about 35% below similar Western materials.

The emphasis has been on producing high performance composites using established techniques, e.g. PAN fibres and epoxy resins. Relatively little work has been done on thermoplastic matrix materials and pitch-based fibres, which are areas of interest in the West.

Research to improve fibre–matrix adhesion is extensive. Dry and wet oxidation techniques and activated and chemically modified carbon fibres have been studied. Work on chemically modified fibres is, in some respects, more advanced than in the West, although this research base has not been fully applied to improving composite properties.

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