Journal of Macromolecular Science, Part A
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597274

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To cite this Article Eaumann, G. and Brownlee, J. L.(1973) 'Tire Cord Application of High-Modulus Fibers Derived from Polyamide-Hydrazides', Journal of Macromolecular Science, Part A, 7: 1, 281 — 293
To link to this Article: DOI: 10.1080/00222337308061141
URL: http://dx.doi.org/10.1080/00222337308061141

J. MACROMOL. SCI.—CHEM., A7(1), pp. 281-293 (1973)

Tire Cord Application of High-Modulus Fibers Derived from Polyamide-Hydrazides

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ABSTRACT

Recent developments in tire design have focused interest on new combinations of properties for fibers to be used in tire cords. Different fiber properties are of importance depending on whether the end use is in bias design, breaker belts, or radial design. X-500 class fibers of polyamide-hydrazides can be produced with a range of property combinations. The textile-like fiber with good tenacity, extensibility, and modulus similar to presently used organic fibers has advantages of greater dimensional stability and heat resistance. The high modulus variant shows better flex life, abrasion resistance, and water resistance than glass. X-500 class fibers can be made stronger and stiffer than glass or steel—when compared in textile units. Data presented show typical prototype X-500 tire cord properties in the greige and the heat-treated form. Experimental tires were made using a polyamide-hydrazide X-500 fiber in the belts of radial and bias constructions. Nylon 66 and polyester were used in the carcasses. Treadwear data showed equivalent performance of the polyamide-hydrazide X-500 belts when compared to glass, and they were less prone to belt separation failures.

INTRODUCTION

In the conventional bias tire each set of reinforcing tire cords lies diagonally from one bead (rim) to the other inside the rubber matrix. To optimize the tire performance, modifications of tire design (ply angle, number of plies, and number of cords), fiber properties, and rubber characteristics can be carried out. Improvements in a desirable property in bead, sidewall, shoulder, or tread area are limited by the close interrelationship and often conflicting requirements of all those areas because there is only one set of cords. Trade-offs and compromise solutions are the only way to achieve improvements.

The advent of belted bias and radial tires focused attention on optimizing separately the design for best performance of the tread and sidewall regions. The obvious next step of using different fiber reinforcements in different parts of the tire followed, bringing an analysis of desired characteristics for each part rather than overall compromises. It also gave impetus to more fundamental studies of the functions and required properties of the different regions of a tire.

The trends in tire design also took into account trends in tire use and customer demands. More super highways brought about higher average speeds and more concern with safety and performance, together with government involvement with labeling and consumer protection.

In addition to passenger vehicles, bus, truck, aircraft, and off-the-road tire use continues to evolve due to greater speeds, loads, and tire life expectations, all in turn requiring tire reinforcements with high performance.

With this background the testing of high modulus fibers of the X-500 type was undertaken to assess their position as new tire cord materials.

ADVANTAGES OF HIGH MODULUS TIRE CORD FIBERS

An important aspect of belted tire construction is the potential increase in tread life than can be achieved. The increased stiffness of the footprint area due to the presence of the belt has been linked with a decrease of treadwear. The rigid belt prevents the wasteful scuffing of the tread rubber and reduces deformations which do not take part in traction, braking, and cornering of the tire. Inherently stiff fibers are thus desirable.

Cords in the casing (sidewall) of a radial tire do not have the criss-cross lay-up of the bias tire, and because of this have special geometrical limitations. This is particularly so in monoply constructions, and for this reason reinforcing cords are required that possess greater stiffness. Fibers with inherent high modulus are therefore advantageous.

COMPARISON OF VARIOUS TIRE CORDS

In order to assess the position of a new fiber, its relationship to existing materials is, of course, relevant. As has previously been shown [1], members of the X-500 family of fibers can be obtained in a range of property combinations. While single filament properties underlie all uses of the fiber, the relevant comparisons here concern actual tire cord constructions. Typical stress-strain curves are shown in Fig. 1 in textile units and in Fig. 2 in engineering units. In the latter the typical textile fibers (rayon, nylon, and polyester) are more clearly separated from the others, i.e., the high-modulus fibers [steel glass and the glass-like PABH-T(G)]. [Note. The fiber used in the tire cords described in this paper is a member of the X-500 family, a generic term denoting high-modulus organic fibers made by Monsanto Co. This fiber is derived from p-aminobenzhydrazide and terephthaloyl chloride. It will be denoted by PABH-T X-500. Its glass-like variant will be distinguished from the textile-like variant by the letters (G) and (T) in parentheses, e.g., PAGH-T(G).] Particularly noticeable is the change of position of the steel fibers in the two figures. For some considerations its high tensile strength and compactness are more relevant than its low tenacity (performance/lb) and work to break.

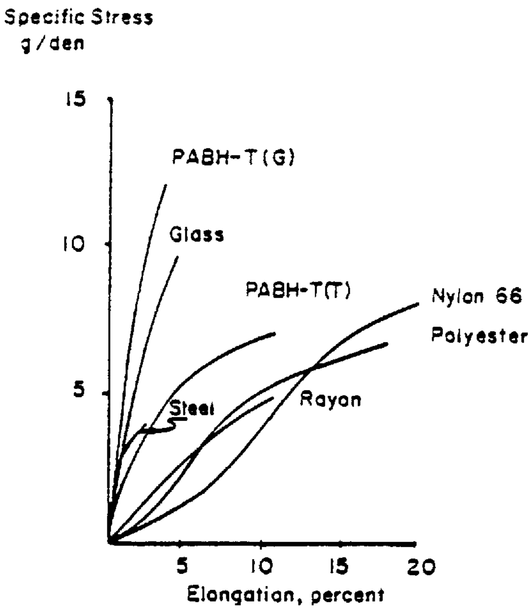

FIG. 1. Curves of specific stress vs elongation. Various typical tire cords.

Table 1 enumerates several parameters of tire cords now in use in passenger tires. The cords listed are "typical" and considerable variations occur between manufacturers depending on spinning and stretching operation or chemical modifications. In addition the performance of the cords is affected by the twist levels and heat treatments. The comparisons attempt to reflect commercially available cords rather than research level cords, except for the X-500 type of cords which are not in commercial use and must be considered as an early research product.

Table 1 also illustrates the very special position of steel reinforcement. Because of the very different diameters and cord constructions, comparisons can be very misleading, especially those of laboratory tests.

PRELIMINARY TESTS ON PABH-T X-500 TIRE CORD

Figures 1 and 2 and Table 1 show that the room temperature values of tenacity, modulus, and elongation bring PABH-T X-500

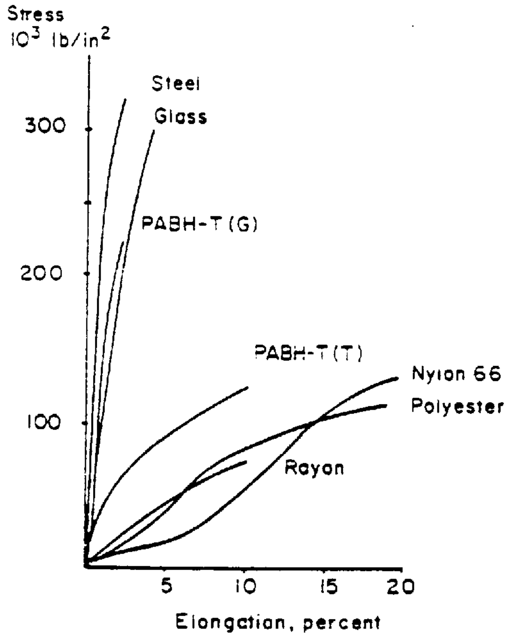

FIG. 2. Curves of stress vs elongation. Various typical tire cords.

right into the range of possible tire reinforcing materials. Its similarity to glass (and steel) make it an obvious first choice as a belt cord for bias or radial belts.

Cords in the casing of radial tires require excellent flex life which in PABH-T X-500 can be achieved in at least two ways: by a reduction in fiber diameter and by lowered crystallinity. Relevant data are shown in Table 2 (the fatigue life of cords can also be considerably increased by increased twist). The last two lines showing the performance of PABH-T(G) of X-500 and glass of similar diameters are especially noteworthy. A low denier or low crystallinity version of PABH-T might also be considered as a candidate for radial sidewall reinforcement. While technically quite feasible, commercially it is a less attractive alternative than the above-mentioned belt application.

For a modern tire, desirable high values of tenacity and modulus at room temperature are not sufficient. It is essential that these apply over the whole range of working temperatures. Future trends are likely to extend this range.

TABLE 1. Physical Properties of Typical Tire Cords (Passenger Cars)

		Material						
Property	Units	Steel	Glass	PABH-T(G) X-500	PABH-T(T) X-500	Rayon	Nylon 66	Poly-ester
Construction		1x5x.0059"	150-10/0	1050/3	1050/3	1650/2	840/3	1000/3
Twist	tpi	3.0	Very low	6/4.5	6/6	12/12	12/12	13/13
Number of filaments		5	2040	540	540	2200	420	500
Total denier (nom)	den	6250	3060	3150	3150	3300	2520	3000
Filament denier	den	1250	1.5	6	6	1.5	6	6
Cord diameter (dipped)	mil	16	25	26	26	28	26	26
Filament diameter	mil	5.9	0.4	0.9	0.9	0.5	1.1	1.0
Specific gravity		7.85	2.55	1.47	1.44	1.53	1.14	1.38

Breaking load	lb	44	62	80	45	35	47	39
Tenacity	g/den	3.2	9.2	11.5	6.5	4.8	8.4	5.9
Ultimate tensile strength	10^3 lb/in.^{2}	320	300	220	120	80	122	104
Ultimate elongation	%	2.5	3.7	2.5	10.0	9.8	19.3	18.5
Modulus	g/den	250	260	500	280	60	40	50
	10^6 lb/in.^{2}	25	8.5	9.4	5.2	1.2	0.6	0.9
Toughness	g/den	0.05	0.25	0.2	0.4	0.3	0.7	0.6
	10^3 lb/in.^{2}	4.9	8.3	3.8	7.4	5.8	10.2	9.9

TABLE 2. Flex Fatigue Endurance (MIT Flex Test) of PABH-T X-500

Material	Fiber: Denier	Fiber: Diameter (mil)	Crystallinity	Cycles to break
PABH-T(E)[a]	6.1	0.95	Very low	16,700
PABH-T(T)	6.7	1.00	Low	8,200
PABH-T(T)	6.7	1.00	Medium	1,900
PABH-T(G)	5.6	0.90	High	140
PABH-T(G)	1.0	0.38	High	1,600
Glass	1.5	0.36	-	125

[a] PABH-(E) is a very high elongation variant of this X-500 composition unsuitable for tire cord use.

Bias tires under freeway use run 100°F (and more in localized areas) above ambient. When tires are overloaded, even greater differentials have been observed. While radials in passenger cars may be running somewhat cooler, truck radials, aircraft tires for frequent landings at high speeds, and off-the-road vehicles with their very heavy reinforcements and need for greater heat dissipation all have similar problems due to heat generation and build-up in tires.

Change of strength with temperature should be small so that the tire safety factor continues to remain high under all conditions and any localized stresses in the cord do not lead to degradation and early failure.

Figure 3 shows trends of tenacity vs temperature and indicates that while organic fibers have similar decreases, PABH-T X-500 continues to show higher strengths than glass below 300°F (150°C) and than steel below 450°F (220°C).

Variations of modulus with temperature should also be small to prevent tire growth during use, or any flatspotting tendency.

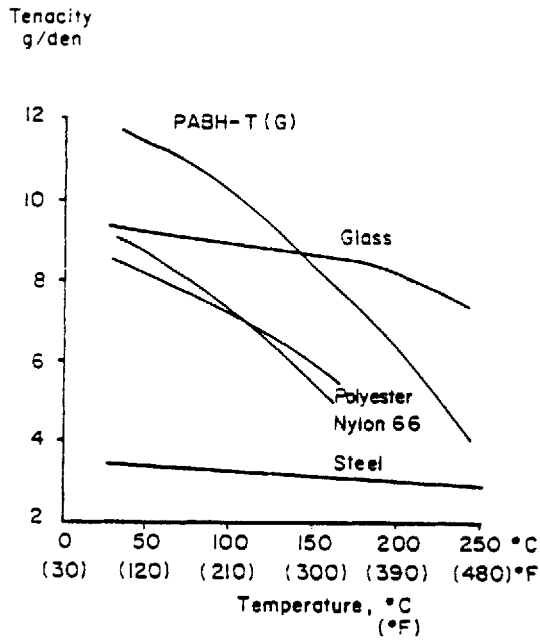

FIG. 3. Variation of cord tenacity with temperature. Various tire cords.

A nonvarying modulus means reinforcement will continue to give designed rigidity in wear, ride, and handling characteristics over the whole working range of temperatures. Figure 4 shows a comparison of behavior of several cords. Both glass and steel show a much smaller dependence of tensile modulus with temperature. However, PABH-T(G) continues to have a much higher modulus than the inorganic fibers up to about 480°F (250°C).

TIRE TEST RESULTS

A preliminary requirement to building successful tires is to develop a good finish/adhesive system between reinforcement and rubber. With inadequate adhesion the cord cannot properly fulfill its function. Intimately connected with this is a suitable finish to be compatible with fiber and adhesive. Results of a

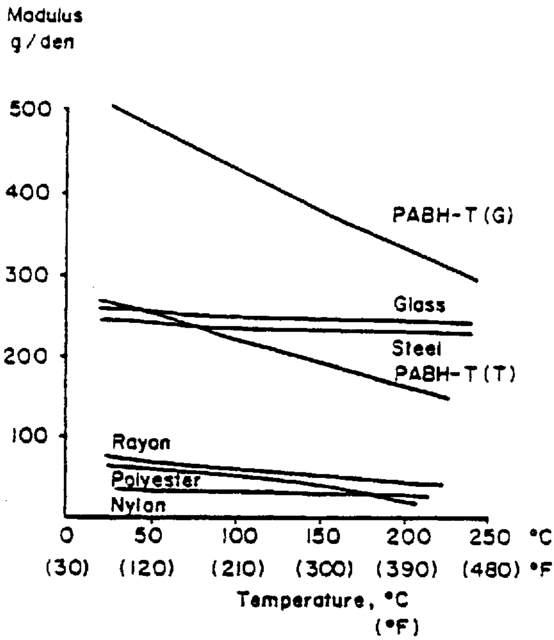

FIG. 4. Variation of tensile modulus with temperature. Various tire cords.

typical trial are shown in a block diagram in Fig. 5. The presence of the finish improved the tenacity and elongation (and hence energy-to-break) for various heat treatments but inadequate adhesion meant a search for another finish. Finally, before optimization experiments were complete, an adequate finish giving acceptable adhesion with conventional RFL adhesive was incorporated into some experimental tires. Six G-78-14 tires were constructed using PABH-T X-500 in the belts. 1050/3 cords composed of 6 dpf filaments had 6x4.5 tpi twist and were laid up at 18 epi. Three of the six tires had nylon-66 casings; the others had polyester casings. A similar set of tires with commercial glass tire cord was built for comparison. In addition, some commercially available polyester/glass tires were bought and similarly tested. Two tires of each set were run on a track to study treadwear and separation resistance. The results for separation resistance are shown in Table 3. No separation occurred in the PABH-T X-500 belted tires which

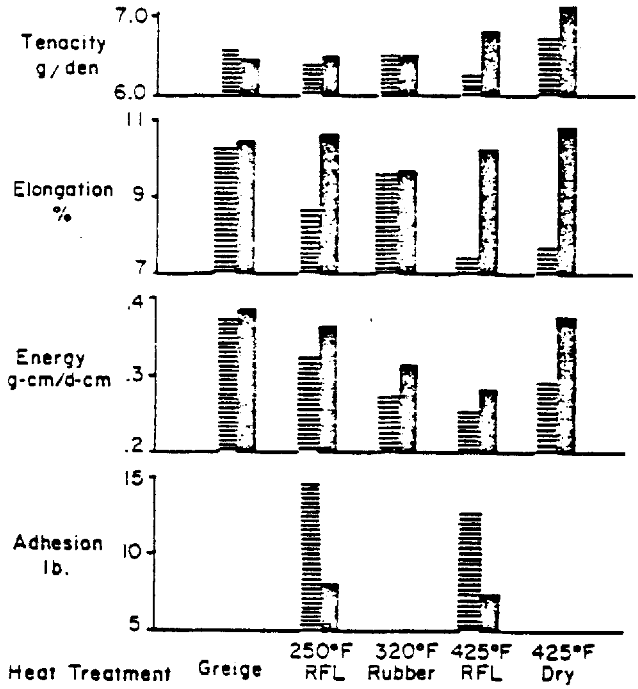

FIG. 5. Block diagrams showing effect of heat treatments on PABH-T(T). Striped blocks = no finish; solid blocks = "O" finish.

had completed 19,000 miles when the test was stopped. Two of the glass belted controls failed because of separation, and one of the commercial tires also failed for the same reason.

Table 4 gives the treadwear data expressed as miles per mil for three tread positions. There was no significant difference between the treadwear on the PABH-T X-500 and the glass belted tires. The commercial tires were somewhat worse.

One tire of each set was submitted to the dynamic plunger test. This test is greatly affected by the belt strength of the tires, and good comparisons between the recorded data are not possible. The glass belts were 50% stronger than the PABH-T X-500 belts. Based on previous tests, PABH-T X-500 belted tires of the same strength of glass would be expected to withstand plunger heights of at least 4 in., which can be considered quite acceptable for such tires. Data are given in Table 5.

TABLE 3. PABH-T X-500 Belted Bias Tires. Separation Resistance Test Mileage 19,000 Miles Maximum

Construction	Mileage	Failure
Nylon/PABH-T	19,000	None
Nylon/PABH-T	19,000	None
Polyester/PABH-T	19,000	None
Polyester/PABH-T	19,000	None
Nylon/glass	19,000	None
Nylon/glass	7,625	Separation, belt edge
Polyester/glass	19,000	None
Polyester/glass	400	Separation, shoulder
Commercial		
Polyester/glass	19,000	None
Polyester/glass	11,750	Separation, off shoulder

TABLE 4. Treadwear of PABH-T X-500 Belted Bias Tires. Test Mileage 19,000 Miles

	Miles/0.001 in. skid loss		
Construction	Inside shoulder	Center	Outside shoulder
Nylon/PABH-T	53.7	73.4	54.8
Nylon/PABH-T	58.3	79.3	59.6
Polyester/PABH-T	<45.5[a]	64.0	48.0
Polyester/PABH-T	<45.5[a]	63.5	48.7
Nylon/glass	54.8	86.0	55.9
Polyester/glass	49.1	62.3	48.3
Commercial			
Polyester/glass	<44[a]	77.2	<44[a]

[a]Smooth.

TABLE 5. Dynamic Plunger Performance. PABH-T X-500 Belted Bias Tires

Construction	Belt strength (lb)	Plunger height (in.)	Energy (in.-lb)
Nylon/PABH-T	1540	3 (>4)[a]	2250 (>4500)[a]
Polyester/PABH-T	1540	3 (>4)	2475 (>4800)
Nylon/glass	2400	3-3/4	3750
Polyester/glass	2400	4-1/4	4462
Commercial	-	4-1/2	5062
Polyester/glass	-	4-3/8	5140

[a]Values in parentheses are estimated for a belt strength of 2400 lb.

CONCLUSIONS AND OUTLOOK

On the basis of these preliminary tests one may conclude that, although the particular X-500 composition used in this study may not be the final, best candidate for a new generation of tire reinforcements, the results are sufficiently encouraging to look in the direction of high-modulus wholly aromatic fibers for a new tire cord material.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Dr. W. B. Black and Mr. R. D. Agee for their active interest and continued encouragement throughout all stages of this work and to Mr. H. S. Morgan for supplying the flex data.

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