ITEM #5

U. S. ARMY NATICK LABORATORIES

NATICK, MASSACHUSETTS

MATERIAL EXAMINATION REPORT

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TITLE:

Constructional Effects on Impact Breaking Strength of Parachute Suspension Lines.

PURPOSE:

To investigate the effects of structure (yarn plying and braiding) on the overall strength of nylon suspension lines (MIL-C-5040b, Type I and Type II) when tested at high strain rates.

CONCLUSION:

1. Braided nylon suspension lines, Type I and Type II of MIL-C-5040b, showed approximately 20% lower strength when tested at impact test speed than when tested at conventional test speed.

2. These lower strength values are real and appear to be due to constructional effects (plying and braiding) which are accentuated at high strain rates and are not due to testing artifacts created by the test instrument.

3. Analysis of the overall losses in stress translation efficiency when going from the basic untwisted ply yarns to the final braided sleeve of Types I and II Cord showed that these losses are greater at impact speed than at conventional speed by a ratio of approximately 2:1.

4. Similar analyses of the losses in stress translation efficiency for the 5/3 plied core yarns of Type II showed similar but greater losses than the braided sleeve structures when tested at impact speeds.

5. Consistent with the above was the observation that breaking strength of knots, in both types of cord, was lower at impact speeds than at conventional speeds.

BACKGROUND:

Impact testing of the textile structures is a relatively new field, especially when compared with conventional quasi-static testing of the same materials. As new impact test equipment is designed and built, it therefore becomes necessary to perform considerable research to develop new testing techniques and to interpret the data obtained by the new instruments.

Much of the previous impact data on textile structures had been developed on structures such as single yarns and rather simple woven structures. These data had led to the hypothesis that an increase in strain rate during testing brings about an apparent increase in strength. Consequently, when tensile tests made in these Laboratories on nylon parachute suspension lines in connection with the AE Project, Safe Service Life of Personnel Parachutes, showed an apparent loss in breaking strength at high strain rates, the results were considered anomalous. Since the tester used, the QMC Impact Tensile Tester, was a newly-designed research instrument, the effect was attributed to testing artifacts possibly caused by the tester itself, especially perhaps the split drum jaws used to hold the specimens.

A thorough study was made of methods to reduce apparent breakage in the jaws: use of jaw padding, jaw lubricants, modification of test drums to hold the specimens, alteration of the specimens themselves, and investigation of frictional heat buildup at the clamps. High speed motion pictures were taken of the specimens as they broke. None of these efforts indicated that the Tester itself was responsible for the anomalous results.

Further, the same effect was observed not only when Type II Cords (375 lbs.) were tested on the QMC Tensile Tester using split-drum jaws, but also when Type IA Cords (100 lbs.) were tested on the FRITS High Speed Piston Tester using flat jaws. Since two different test instruments with two different types of jaws gave the same effect, it was concluded that the results were not an artifact caused by the equipment, but an inherent characteristic of the textile structures being tested. The cords tested consisted of a braided sleeve, with or without a plied yarn core. This led to an analysis of the effect of braiding and plying on the stress translation in the textile structures which produces this overall loss of strength at high strain rates.

The results of the analysis are presented in this report.

MATERIALS:

This study was performed on two braided nylon cords conforming to MIL-C-5040b. They were Type IA, a coreless braided cord with a minimum rated strength of 100 lbs. and Type II, a braided sleeve containing four yarns within it (core yarns) and having a rated strength of 375 lb. (min).

Specification requirements for both cords are listed in Table I.

EXPERIMENTAL PROCEDURE:

The tests performed in this study involved the breaking strength of the different components in the structure of two suspension lines. Strengths for each step in the structural process were investigated at both high and low test speed. The procedure which was followed for the outer sleeve portion of the cords was to (1) begin with a large amount of braided cords of each Type (IA and II) and test a portion of these in final form at high and low speed, (2) unbraid the remaining cords and test a portion of the individual ends at both speeds, (3) unply the remaining ends and test the individual plies, and (4) untwist the remaining plies and test at both speeds so that for the basic unplied yarns we have a set of readings for both the twisted form and the zero twist form. No attempt was made to test the individual filaments from the zero twist basic yarns.

A similar procedure was used for the core yarns of the Type II Cord which is a 5/3 ply.

The unplying and untwisting operations were performed by the use of a Twist Tester manufactured by the Alfred Suter Co. of New York. It was found to be less tedious and time consuming in the unplying process to remove the individual plies from the twist tester and allow them to rest freely on a bench rather than attempt to hold their entire amount of twist. The amount of twist which remained in the samples by this method was fairly consistent although it did not conform to the specification requirement for twist at that particular point in the constructional process.

Breaking strength tests were performed on three test instruments; the Instron Tensile Tester, the FRITS High Speed Piston Tester, and the QMC High speed Impact Tester. All conventional or slow speed tests were made on the Instron using a crosshead speed of 5 in/min. The choice of high speed tester for a particular cord or component was based on the strength of the item. The FRITS Tester has a maximum capacity of 250 lbs. and is considered accurate in the low strength ranges such as found for the basic yarns, whereas the QMC Tester with a maximum capacity of 4000 lbs. is better suited to higher strengths as found for the complete cords. High speed tests were run at 20 ft/sec.

All measurements on the FRITS Tester were made using flat jaws, either 1 x 3 inch stainless steel or 1 x ½ inch aluminum. All tests performed on the QMC Tester were made using aluminum split drum jaws. Slow speed Instron tests were made using flat 1 x 3 inch jaws or split drum jaws, whichever type was used for the high speed tests on the same item.

Knot strength tests were made on all three test instruments using both flat and split drum jaws. A single overhand knot was tied in the center of each test specimen.

The majority of the groups tested consisted of 5 specimens with gage lengths of 5 inches for flat jaw tests and 32 inches for split drum jaw tests.

RESULTS AND DISCUSSION:

Table I lists the specification requirements for the two nylon cords tested. It can be seen that the sleeve yarns for both Types IA and II have identical requirements, the only difference between the two sleeves is that the Type II has 32 ends braided while the Type IA has 16. The Type II Cord also has 4 core yarns making it much stronger and heavier overall than the type IA which is coreless. It should be pointed out that the amount of twist in the test specimens as recorded in Table 2 does not agree completely with the twist required in Table 1. The reason for this is that it was found to be more practical to allow the samples to relax freely after being unbraided, or unplyed, rather than to attempt to hold the full amount of twist through each step in the process of breaking down the cords. Since this report is only intended to show the trends that exist with structure and strain rate, this was considered to be a satisfactory method. Thus quantitative results, although showing good correlation, are only considered to be approximations.

The data recorded in Table 3 traces the stress translation efficiency for each step in the structure of the braided sleeves and the core yarns. In computing translation efficiency by the ratio of actual to theoretical breaking strength, the theoretical breaking strength was based on the strength of the most basic untwisted yarns in the structure at high or low speed. For example, the most basic untwisted yarns in the sleeve of Type II cord show breaking strengths of 3.48 lb. at low speed and 4.48 lb. at high speed; therefore, theoretically, when these yarns are twisted, they should have these same strengths. When they are three plied, they should have 3 x 3.48 lbs. at low speed and 3 x 4.48 lbs. at high speed, etc. The true significance of the data in Table 3 is found when tracing the values from basic yarn to complete sleeve. It is seen that the most basic yarn exhibits greater strength at high speed than at low which is a generally accepted result for nylon 66. With 6-9 turns of twist, the strengths are increased at both speeds, also an expected occurrence. However, when the basic yarns are three plied we see that although the actual strength is higher at high speed there is actually an approximate 2:1 loss in stress translation efficiency at high speed. The additional loss in efficiency at the braiding process at high speed is sufficient to result in a lower actual breaking strength at high speed than at low speed for the braided sleeve.

The data in Table 3 for core yarns shows similar trends of greater losses in efficiency at high speed than at low speed as the structure becomes more complex. The importance of this data is that the core yarn structure is different from that of the sleeves yet similar trends in efficiency are inherent.

The analysis in Table 4 is intended to give a closer approximation of the losses in efficiency due to each process. This was done by computing theoretical strength on the basis of the actual strength of the previous process. From the results it appears that braiding has the greatest effect on the high speed to low speed ratio of efficiency losses; however, a nonuniformity does exist which, it is felt, could be improved by a more controlled test program. Yet, as seen from Figure 2, qualitative trends do exist which approximate those found in Table 3 (Figure 1).

Knot strength tests, summarized in Table 5 were included in this work to show that lower strength at high speed is obtained even from an unrelated structure such as that formed by an overhand knot. Consistency in the results for the three samples is shown by the close agreement of the high speed to low speed efficiency ratios in Table 5.

The basic and most significant result of this study was that, although the individual components of these two cords have a higher breaking strength at high strain rate than at low strain rate, the cords in their final braided form exhibit lower strengths at high strain rate. This indicates that the structural effects in going from the basic yarn component to the braided construction are greater at high rates of loading. The validity of this phenomenon is significantly emphasized by the following observations:

1. Nylon coreless cord (Type 1A, MIL-C-5040b) which has a construction very similar to the Type II cord except on a smaller scale (100 lb strength) and without core yarns, exhibits similar losses in strength at high speed using a different test instrument and a different type jaw.

2. Strength and translation efficiency at high and low speed at the different stages in the structure of these two cords show a close correlation even though tested on two different test instruments and with two different clamping methods.

3. The fact that structural effects are magnified at high speed is further shown by tests on core yarns from Type II cords which lose strength and show greater losses in translation efficiency at high speed due to two plying processes. This parallels the trends shown for the braided construction of the two sleeves.

4. Knot strengths of the two cords and the core yarns are lower at high speed than at low speed which further indicates that the trend of lower strength at high speed due to structure is valid and alleviates any doubts about jaw effects since all breaks occurred at the knot in the center of the specimen.

The decrease in efficiency with increasing complexity of structure is a well known phenomenon caused by mechanical effects (shearing, friction, etc.) between adjacent components of the structure. It is believed that the trends obtained in this report are caused by such mechanical effects which are accentuated at the high strain rate, possibly due to a combination of the test speed and the high extensibility of nylon 66. Molecular orientation and crystallinity effects which, although not as yet clearly defined, are manifest in the increased strength with increased strain rate for basic fibers, are apparently overcome by mechanical effects as the structure is made more complex.

The trends in stress translation efficiency obtained through this work can only be interpreted as applicable to the particular materials and structural configurations examined. Very limited tests performed at these Laboratories indicate that similar results may possibly be obtained from an investigation of nylon 66 in webbing form. There is also some evidence that cotton fiber in webbing form will not show these trends at high strain rate.

It is felt that analyses of this type will yield results which will vary both qualitatively and quantitatively with material and construction; therefore, no broad generalities should be assumed based on the findings of this study.

Table 1

Specification Requirements for Nylon Cords Used as Test Specimens

	MIL-C-5040b			
	Type IA		Type II	
	Core	Sleeve	Core	Sleeve
Yarns				
Denier	-	210	210	210
Ply	-	3	1st - 5 final - 3	3
Twist (turns per inch)				
Spin	-	7.0-9.5	1 appx	7.0-9.5
Ply	-	5-7	1st - 10-16 final - 6-8	5-7
Number of Yarns	-	-	4-7	-
Picks per inch	-	26-28	-	26-28
No. of Carriers and Ends per Carrier	-	16/1	-	32/1 or 36/1
Breaking Strength (lb) (min)		100		375
Elongation (%) (min)		30		30
Yards per Pound of Cord (min)		350		105

Table 2

Breaking Strength at High and Low Speeds and Test Condition Data

Type II Cord	Breaking Strength (lbs) Low Speed	Breaking Strength (lbs) High Speed	Appx. Twist (tpi)	Test Instrument Low Speed (5 in/min)	Test Instrument High Speed (20 ft/sec)	Type Jaw Low Speed	Type Jaw High Speed
Sleeve							
Basic Yarns (Untwisted)	3.48	4.48	0	Instron	FRITS	Flat 1x3	Flat 1x½
Basic Yarns (Twisted)	3.60	4.58	6-9 Z	Instron	FRITS	Flat 1x3	Flat 1x½
Basic Yarns (3 plied)	10.1	12.0	7.5 S	Instron	FRITS	Flat 1x3	Flat 1x3
Complete Sleeve (32 yarns braided)	277	247	-	Instron	QMC	Split Drum	Split Drum
Core Yarn							
Basic Yarn (Untwisted)	3.41	4.10	0	Instron	FRITS	Flat 1x3	Flat 1x½
Basic Yarn (Twisted)	3.48	4.23	2-4 Z	Instron	FRITS	Flat 1x3	Flat 1x½
Basic Yarn (5 plied)	17.1	17.8	4 S	Instron	FRITS	Flat 1x3	Flat 1x3
Core Yarn (5/3 plied)	48.3	42.8	6 Z	Instron	FRITS	Flat 1x3	Flat 1x3
Complete Cord (Sleeve plus 4 cores)	446	355	-	Instron	QMC	Split Drum	Split Drum
Type IA Cord (Coreless)							
Basic Yarn (Untwisted)	3.49	4.20	0	Instron	FRITS	Flat 1x3	Flat 1x½
Basic Yarn (Twisted	3.60	4.24	3.5 S	Instron	FRITS	Flat 1x3	Flat 1x½
Basic Yarn (3 plied)	10.7	12.0	5 Z	Instron	FRITS	Flat 1x3	Flat 1x3
Complete Cord (16 yarns braided)	136	112	-	Instron	FRITS	Flat 1x3	Flat 1x3

Table 3

Translation Efficiency at High and Low Speed of Each Process in Structure of Nylon Braided Cords - Basic Yarn Strength Basis

Type II Cord	Actual Breaking Strength (lbs) Low Speed	Actual Breaking Strength (lbs) High Speed	Theoretical* Breaking Strength (lbs) Low Speed	Theoretical* Breaking Strength (lbs) High Speed	Translation Efficiency (%) Low Speed	Translation Efficiency (%) High Speed
Sleeve						
Basic Yarns (Untwisted)	3.48	4.48	3.48	4.48	100	100
Basic Yarns (Twisted)	3.60	4.58	3.48	4.48	103	102
Basic Yarns (3 plied)	10.1	12.0	10.4	13.4	97.1	89.6
Complete Sleeve (32 yarns braided)	277	247	334	430	82.9	57.4
Core Yarn						
Basic Yarn (Untwisted)	3.41	4.10	3.41	4.10	100	100
Basic Yarn (Twisted)	3.48	4.23	3.41	4.10	102	103
Basic Yarn (5 plied)	17.1	17.8	17.1	20.5	100	86.8
Core Yarn (5/3 plied)	48.3	42.8	51.2	61.5	94.3	69.6
Complete Cord (Sleeve plus 4 Core Yarns)	446	355	539	676	82.7	52.5
Type IA Cord (Coreless)						
Basic Yarn (Untwisted)	3.49	4.20	3.49	4.20	100	100
Basic Yarn (Twisted)	3.60	4.24	3.49	4.20	103	101
Basic Yarn (3 plied)	10.7	12.0	10.5	12.6	102	95.2
Complete Cord (16 yarns braided)	136	112	168	202	81.0	55.4

*Based on breaking strength of basic untwisted yarn for each group at the speed indicated.

Table 4

Translation Efficiency at High and Low Speed of Each Process in Structure of Nylon Braided Cords - Previous Process Strength Basis

	Actual		Theoretical*			
	Breaking Strength (lbs)		Breaking Strength (lbs)		Translation Efficiency (%)	
Type II Cord	Low Speed	High Speed	Low Speed	High Speed	Low Speed	High Speed
Sleeve						
Basic Yarns (Untwisted)	3.48	4.48	3.48	4.48	100	100
Basic Yarns (Twisted)	3.60	4.58	3.48	4.48	103	102
Basic Yarns (3 plied)	10.1	12.0	10.8	13.7	93.5	87.6
Complete Sleeve (32 yarns braided)	277	247	323	384	85.8	64.3
Core Yarn						
Basic Yarn (Untwisted)	3.41	4.10	3.41	4.10	100	100
Basic Yarn (Twisted)	3.48	4.23	3.41	4.10	102	103
Basic Yarn (5 plied)	17.1	17.8	17.4	21.2	98.3	84.0
Basic Yarn (5/3 plied)	48.3	42.8	51.3	53.4	94.2	80.1
Complete Cord (Sleeve plus 4 Core Yarns)	446	355	470	418	94.9	84.9
Type IA Cord (Coreless)						
Basic Yarn (Untwisted)	3.49	4.20	3.49	4.20	100	10[illegible]
Basic Yarn (Twisted)	3.60	4.24	3.49	4.20	103	10[illegible]
Basic Yarn (3 plied)	10.7	12.0	10.8	12.7	99.1	94.5
Complete Cord (16 yarns braided)	136	112	171	192	79.5	58.[illegible]

*Based on breaking strength of structure at prev[illegible] process at speed indicated.

Table 5

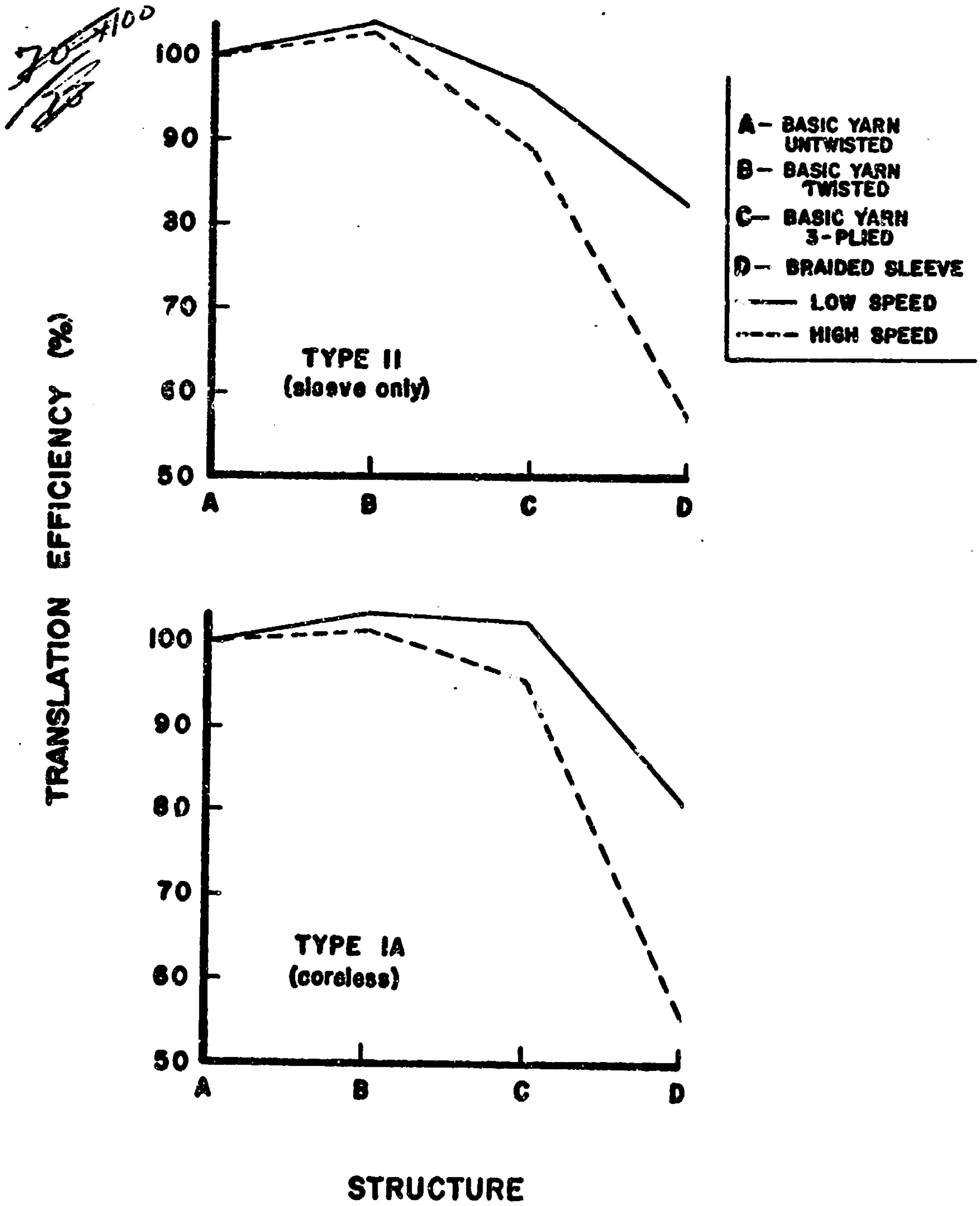
Knot Strengths of Braided Cords at High and Low Speed

	Type IA	Type II	
	Complete Cord	Core Yarn	Complete Cord
Low Speed			
Theoretical* B.S. (lb)	168	51.2	539
Knot B.S. (lb)	79.7	29.0	207
Translation Efficiency(%)	47.4	56.6	38.4
High Speed			
Theoretical* B.S. (lb)	202	61.5	676
Knot B.S. (lb)	70.0	26.1	193
Translation Efficiency(%)	34.7	42.4	28.6
High Speed Eff. / Low Speed Eff.	0.73	0.74	0.74

*Based on breaking strength of basic untwisted yarn at speed indicated.

FIGURE I

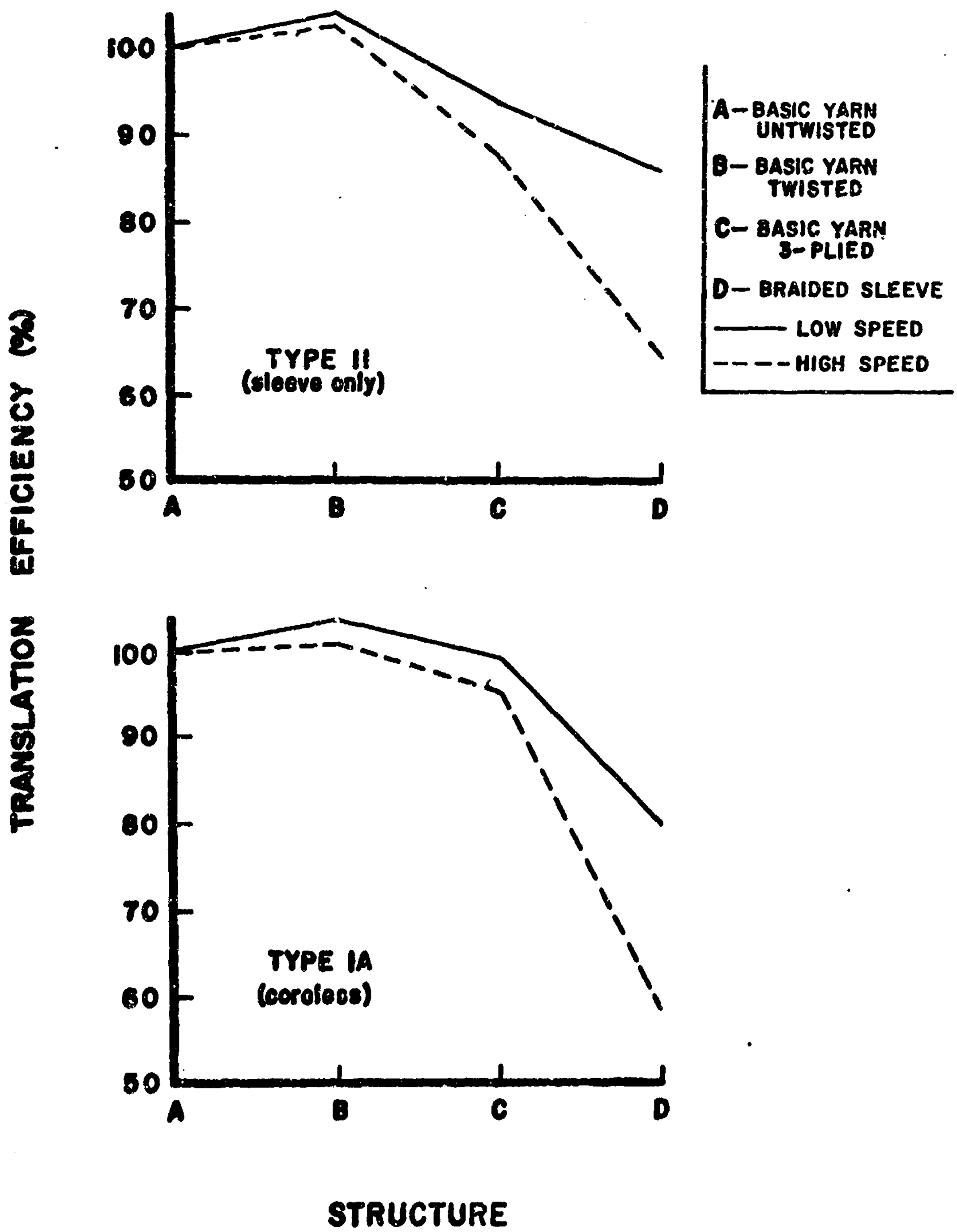
LOSSES IN TRANSLATION EFFICIENCY AT HIGH & LOW SPEED FOR SUSPENSION LINE SLEEVE



NOTE:
THEORETICAL B.S. FOR EACH PROCESS BASED ON THE B.S. OF STRUCTURE "A"

FIGURE 2

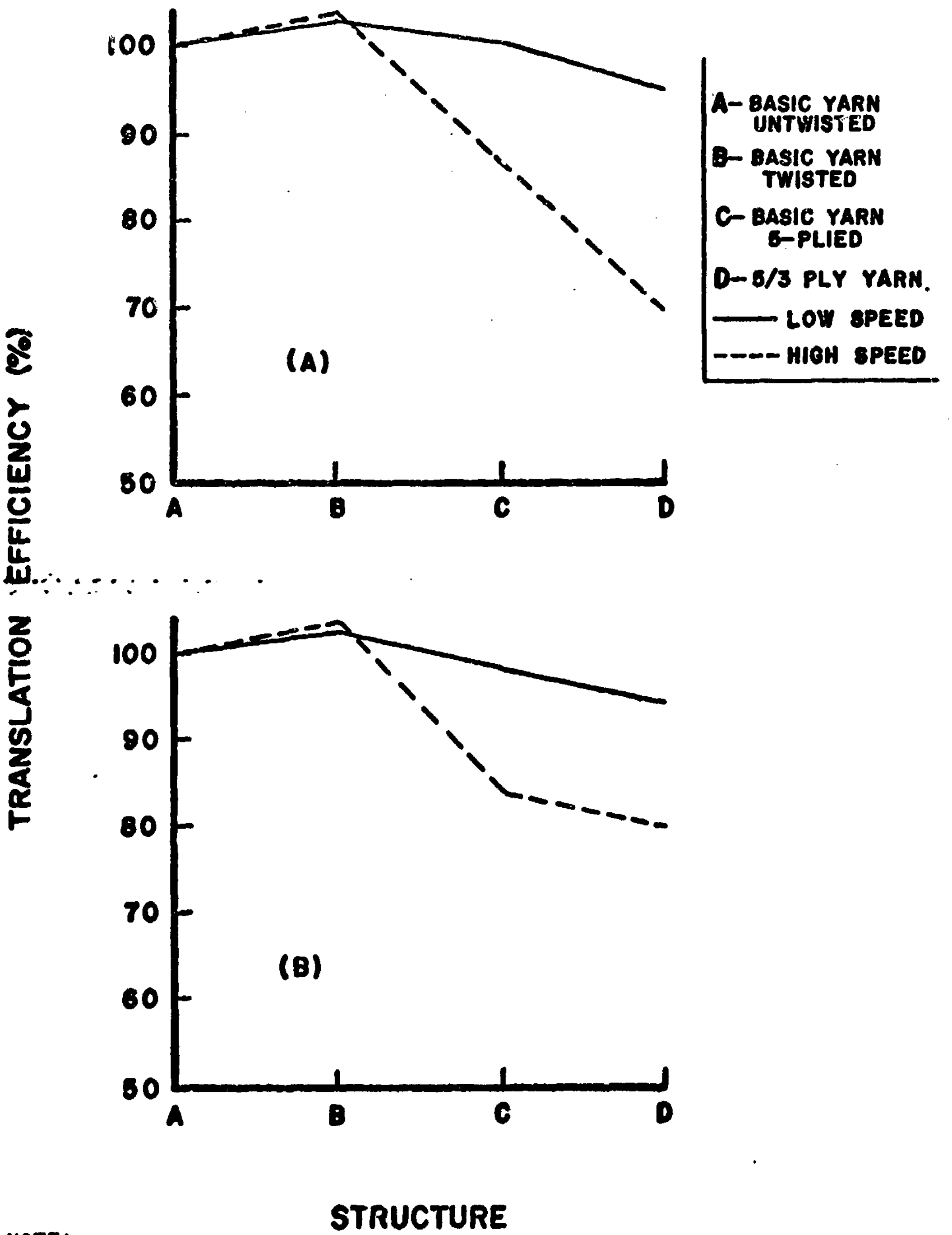
LOSSES IN TRANSLATION EFFICIENCY AT HIGH & LOW SPEED FOR SUSPENSION LINE SLEEVE



NOTE:
THEORETICAL B.S. FOR EACH PROCESS BASED ON THE B.S. OF THE PREVIOUS STRUCTURE

<u>FIGURE 3</u>

LOSSES IN TRANSLATION EFFICIENCY AT HIGH & LOW SPEED FOR SUSPENSION LINE CORE YARN



<u>NOTE:</u>
(A)-BASED ON B.S. OF STRUCTURE "A"
(B)-BASED ON B.S. OF PREVIOUS STRUCTURE