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Twist Liveliness of Yarn Taken from Finished Fabrics

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1. Introduction

Twist liveliness of yarns is of interest to the STARFISH project for at least two reasons. Firstly because it determines the spirality of single jersey fabrics and secondly because it determines the loop shape and hence the dimensions of all knitted cotton fabrics. Previous work has established that the twist liveliness of grey yarns is directly related to the number of turns per metre in the yarn but that the liveliness is reduced by wet treatments such as dyeing. The yarn structure may also be of some importance (e.g. rotor vs. ring yarns).

We have also established that spirality in single jersey is reduced by wet processing and that the reference dimensions (i.e. the basic loop shape) are altered by wet processing. Presumably, at least a part of these changes are brought about by changes in the twist liveliness of the yarn in the fabric. Therefore it is conceivable that the changes in the dimensions of finished fabrics could be (partly) predicted by the changes in twist liveliness of the yarns. In other words, twist liveliness should be an input parameter for the STARFISH equations. Indeed it may be the key to our so-called Finishing Factor.

In order to test this hypothesis it is first necessary to be able to measure the twist liveliness of the yarn in finished fabrics and then to relate changes in twist liveliness to changes in fabric dimensions.

The purpose of the work reported here was to see whether, in principle, reasonable results can be obtained on yarn withdrawn from finished fabrics using our standard twist liveliness test. The experimental work was carried out by Eva Tobisson, a visiting technician from TEFO, during the summer of 1986.

2. Experimental

Six single jersey fabrics were selected. They had been part of the K1 (Spirality Trial) project. All had been made from 28 Ne Z twist ring yarns and knitted on the same 24 gauge machine. Two of the fabrics had been knitted with yarn having a nominal twist factor of 3.0, two with a twist factor of 3.5 and two with 4.0. Within each pair there was one fabric with a relatively short stitch length (2.91 mm) and one with a relatively long one (3.54 mm). The original yarns were also available in package form. The fabrics had been dyed in a Rotostream jet and finished open-width.

Sample identification was as follows:

No	**Nominal Twist Factor**	**Nominal Stitch Length**
1	3.5	2.91
2	3.5	3.54
3	3.0	2.91
4	3.0	3.54
5	4.0	2.91
6	4.0	3.54

Yarn was unravelled from the fabric to the extent of about 110 cm, taking care not to lose any twist. This was then mounted on the twist liveliness tester in the usual way, i.e. pretensioning at 2 g/tex before clamping. This pretension was found to be sufficient to remove all of the yarn crimp. For each fabric sample, and yarn package, ten measurements were made at each of five different loop loading weights, namely 2, 4, 8, 16, and 33 g. This is a much wider range of loads than we have used before.

3. Results

The means, 95% confidence limits, and accuracies are given in *Table 1* for the yarns from cone and in *Table 2* for the yarns from fabric. The mean data are plotted in *Figures 1 and 2*.

Apart from the better reproducibility of the grey yarn data, four points are immediately obvious.

Firstly, the values for the grey yarns are significantly higher than those for yarn taken from finished fabrics.

Secondly, there is a pronounced curvature in the relationship between load and twist liveliness which we have not seen before. This is presumably because of the restricted load ranges used in earlier work.

Thirdly the values for the grey yarns having nominal twist factor 4.0 are virtually inseparable from those for the 3.5 twist factor, whereas for the yarns taken from finished fabric there is a clear separation.

Fourthly, for the yarns taken from finished fabrics, those which come from the tighter fabrics almost always have less twist liveliness than those from the slacker fabrics. The differences are small but they are consistent over almost all twist factors and loads.

These four points will be discussed in turn.

4. Discussion

4.1 Relationship between grey and finished yarns

As expected, twist liveliness is lower in the finished yarns than in the grey ones. It would be convenient if the difference were consistent and reproducible so that it could be predicted. Below are given the ratios of finished/grey twist liveliness for the three different yarns. Values for the finished yarns were first averaged over the two fabric tightnesses.

Yarn			**Load, g**		
	2	**4**	**8**	**16**	**33**
3.0	0.47	0.47	0.61	0.68	0.72
3.5	0.65	0.67	0.72	0.77	0.70
4.0	0.78	0.93	0.98	0.95	0.81

As might be expected, the ratio is lower for the lower twist factor indicating (presumably) a greater degree of stress decay caused by the wet processing. The ratio is also lower at lower loading levels which presumably is because at low loads the greatest part of the twist liveliness is due to unrelieved torque. At high loads, the greatest part is due to the applied tension which is the same for all three yarns. It follows that the greatest discrimination between the different yarns (and presumably between different wet processes) should also be found at low loads and indeed the data do support this prediction.

Figure 3 shows the plot of *T/L* for the grey yarns against that for the yarns from finished fabrics. Since any curves through these data must pass through the origin, a family of S-shaped curves has been drawn by hand. They confirm that a greater degree of stress relaxation has occurred in the two yarns having the lower twist factors, which indeed are rather close to each other compared to the high twist yarn, in which stress decay has apparently been much less.

In order to discover whether these relationships are predictable we would have to do a great deal more testing. Visual inspection of the curves supports the intuitive hypothesis that the amount of stress decay (and hence the degree of potential change in loop shape) should be an exponential function of the twist factor.

4.2 Relationship between load and twist liveliness

The discovery of significant curvature in the load-liveliness relationship (*Figures 1 and 2*) complicates the analysis considerably. It has to be remembered that there is no value for us in probing fundamental yarn property relationships because we cannot accept inputs such as yarn bending stiffness and torsional stiffness as inputs for STARFISH. We need to satisfactorily model the data in terms of simple parameters such as tex, stitch length and twist.

After drawing smooth curves through the data by hand one has an impression of a family of exponential functions which only differ from each other in two respects, namely the intercept at zero load and the levelling off (maximum) value. In the case of the grey yarns both the intercept and the maximum seem to be determined by the twist factor. In the case of the yarns from finished fabrics, there is a clear possibility that the fabric tightness also plays a role. In fact, with results from only three yarns, the effect of tightness is not certain because the differences are mainly within experimental error. Therefore, in the rest of this section the problem of the fabric tightness has been shelved by averaging the liveliness of yarns from finished fabrics over the two tightnesses.

For a preliminary analysis of the relationship between load and liveliness, the following model was chosen on an intuitive basis.

$$T/L = I + A \cdot TF\,[1 - \mathrm{Exp}(-b \cdot Load)] \qquad (1)$$

where: I is the intercept at zero load
TF is the actual twist factor of the grey yarns
A is a constant which determines the maximum T/L
b is the rate constant which governs the curvature of the relationship.

The actual twist factors were 2.92, 3.41, and 4.02. From the hand-drawn curves, it was possible to get a rough estimate of *I* for each yarn and these estimates are shown below.

Twist Factor	**Intercept**	
	Grey	**Finished**
2.92	20.5	6.5
3.41	23.0	17.5
4.02	23.0	21.0

When these intercepts are plotted against the actual twist factors we find two more curved relationships (*Figure 4*) which could also be exponentials of the following form

$$I = C\{1 - \mathrm{Exp}[-d(TF - tf)]\} \qquad (2)$$

where: C is a constant which determines the maximum I
d is the rate constant
TF is the twist factor
tf is that level of twist factor which gives $I = 0$ i.e. zero torque in the yarn at zero load

(In fact of course these curves should presumably be S-shaped as they must pass through the origin but computation is made much simpler by fitting a simple exponential.)

In order to test the usefulness of these models the following procedure was adopted.

1. The HP85 was programmed to evaluate equation (2) over the range of twist factors 1.5 to 5.0, allowing the operator to suggest values for the three unknown parameters. The outputs were plotted and compared with the estimates for intercepts, *I*, listed above. Goodness of fit was judged visually since there is not enough experimental data to make a statistical comparison worthwhile. The following were found to be reasonable values for the parameters.

	Grey	**Finished**
C	24	25
d	1.5	1.5
tf	1.75	2.8

The rate parameter, *d*, could be made identical for both series and the maximum parameter, *C*, came out very similar. Thus the main determinant for the curve was the parameter *tf* which is an indirect indication of the amount of stress decay which has occurred in the yarn as a result of storage or wet processing.

2. The HP85 programme was then amended to include the evaluation of equation (1), with the value of *I* being calculated from equation (2) with the *C*, *d* and *tf* parameters fixed at the values given above. As before, the outputs were compared with the experimental values (this time the values for *T/L*) for various choices of the unknowns *A* and **b**, and the goodness of fit was judged by eye. The following were found to be reasonable values.

TF	**Grey**		**Finished**	
	A	***b***	***A***	***b***
2.92	20	0.05	18	0.05
3.41	22	0.05	16.5	0.05
4.02	20	0.05	16	0.05

Once again it was found that the "rate" parameters could be identical and the "maximum" parameters were similar. The results of this analysis are shown in *Figures 5 and 6* where the output from equation (1) is shown drawn through the experimental data.

3. Finally, the problem was given to the multiple linear correlation analysis (Marquard) of the Tektronix Statistics Software with the rate constants fixed at the values chosen above, and operating on all three yarns as a single data set.

i.e. rate constant equation (2) = 1.5
rate constant equation (1) = 0.05

This leaves the software with only three parameters to optimise - we have found that if more than three parameters are involved then large errors can arise. Results were as follows.

	Grey	**Finished**
C	25.3 ± 2.9	24.5 ± 1.2
tf	1.69 ± 0.5	2.65 ± 0.04
A	19.5 ± 1.2	16.0 ± 0.5

The multiple correlation coefficients for these equations are r = 0.980 for the grey yarns and r = 0.995 for the yarns from finished fabrics. Measured vs. predicted values are plotted in *Figures 7 and 8.*

In this final case the values for *A* and *C* represent best-fit averages over the three twist factors which may not be acceptable approximations for prediction purposes. The changes in these two parameters from grey yarns to finished are again an indication of the amount of stress relaxation which has occurred in finishing.

From previous work we can be pretty certain that the parameter *A* will be directly affected by the yarn count and the parameter *C* may well be. Furthermore it could be that the twist factor is not the best independent variable to choose for prediction purposes - maybe the number of turns per metre would be better.

However, it is not worthwhile to continue the analysis any further at this stage; all that was necessary was to show that well-defined relationships exist so that, when adequate data become available we have some hope of being able to predict the influence of twist liveliness in the grey yarn upon dimensional properties after finishing.

4.3 Differential effect of twist factor

At the outset it was noted that the *T/L* values for the grey yarns having nominal twist factors 4.0 and 3.5 were virtually indistinguishable, whereas with the yarns from finished fabric the corresponding *T/L* values were well separated. This can now be explained in terms of differential stress relaxation in storage and in finishing.

Twist liveliness in grey yarns depends on the amount of twist inserted into the yarn at the spinning machine and the amount of stress decay which occurs during storage. These yarns are several years old and our twist liveliness test has changed in the interim so it is not possible to compare old and new results exactly. However, for what it is worth, the comparison is as follows (current test data are interpolated for a loop load of 10 g).

Yarn	**Original Test**	**Current Test**	**C/O**
3.0	42	42	1.00
3.5	50	46	0.92
4.0	58	47	0.81

It would seem that there has been little or no drop in liveliness for the least lively yarn but a relatively greater drop at higher twist factors. This has brought the most highly twisted yarn much closer to the middle one and the total range much narrower.

This does not mean that the range should also be narrower for the yarns taken from finished fabric because the stress relaxation due to wet processing will have been far greater than that due to storage of the grey yarns. The fact that all three finished yarns are still well separated in *T/L* values presumably means that further dry relaxation during storage of the finished fabrics has been either very small or less sensitive to the original twist, or both.

Nevertheless the twist has certainly affected the amount of stress relaxation brought about by finishing which has been much less for the highly twisted yarn than for the softer ones.

4.4 Effect of fabric tightness

The influence of tightness was ignored in the analytical section because the differences are generally too small to be sure they are real.

The average difference in *T/L* for the same yarn taken from the tight and slack fabrics is 3.02 with a standard deviation of 3.1. The grand average of the 95% confidence limits of *T/L* is about 2.3 ± 0.8. Thus the differences between fabrics are, on the average, about the same size as the "noise" in the data.

However the trend in the differences is rather consistent so we must be prepared for the probability that the fabric tightness affects the results of the twist liveliness test on yarns removed from the finished fabrics.

The table below shows the differences and also shows the results of averaging over loads and over twist factors.

Yarn	**Load, g**					**Mean**
	2	**4**	**8**	**16**	**33**	
3.5	-1.2	3.15	-0.05	3.6	7.3	**2.56**
3.0	8.15	2.05	4.25	0.45	3.3	**3.64**
4.0	-1.8	0.9	4.75	7.45	3.05	**2.87**
Mean	**1.72**	**2.03**	**2.98**	**3.83**	**4.55**	**3.02**

There is no obvious trend with respect to twist factor but a clear progression with the loop loading weight is apparent when the data are averaged over yarns. This relationship is shown in *Figure 9* where an arbitrary curve has been drawn through the origin. One could just as easily draw a curve with a positive intercept.

The curve has been drawn through the origin for the following reasons. In these results the yarns taken from the tighter fabrics gave lower values for twist liveliness. This is the opposite to what would be expected if the tightness of knitting were inhibiting stress relaxation. Therefore we may assume that the differences in *T/L* are not due to differences in relaxation. Therefore the curves of *T/L vs. Load* for a given yarn should have the same intercept at zero load. Therefore the curve of *δT/L vs. Load* should pass through the origin.

Another factor which influences *T/L* is the yarn diameter. For the same twist factor, a heavier yarn count will yield lower *T/L* values. In previous work (*Research Record 212*) we found the following results for a series of yarns with twist factors in the region of 3.5.

Ne	**T/L**
20	41
28	50
34	54
42	61

These data are shown plotted in *Figure 10* with a hand-drawn curve through the origin which, once again, looks like a simple exponential function. If we compare our average *T/L* difference (interpolated to the standard 10 g load) of about 3.2 units with the curve of *Figure 10*, we find that this difference corresponds roughly to a change in yarn count from 28 Ne to 25 Ne.

Now, the diameter of cotton knitting yarns, in cm, is given approximately by:

$$d = 2.54 / (24\sqrt{Ne})$$

therefore a 28 Ne yarn has a diameter of about 0.020 cm and one of 25 Ne about 0.021 cm. This is about a 5% change. The difference in stitch length between the two original fabrics was 0.354 to 0.291, a change of about 18%. If a change in yarn diameter is the cause of the change in twist liveliness, we have to explain why a smaller loop length would result in a greater (apparent) diameter. Of course, the diameter itself is not the sole cause of the relationship shown in *Figure 10*, the torsional and bending stiffness of the yarns are at least as important.

If the degree of stress relaxation in the finished fabrics is great enough, then the shape of the loops will be set into the yarns to some extent. When we perform the twist liveliness test, we first straighten the yarn and then allow it to twist around itself. Any setting of the loop shape means that a certain amount of force has to be dissipated in straightening the yarn. The amount of force required will be roughly proportional to the number of loops present. For a constant test length there will be more loops present in the yarn taken from the tighter fabric. Thus the twist liveliness may well be reduced in proportion to the reciprocal of the loop length. This is a prediction which can be tested when more data are available.

4. Conclusions

1. Use of our standard twist liveliness test on yarns taken from finished plain jersey fabrics is feasible. The test values are less reproducible than those obtained on grey yarns from cones. This means that a greater number of specimens should be tested - maybe 15 or 20 instead of 10.
2. Twist liveliness in yarns taken from finished fabrics is lower than that of the original grey yarns. It seems likely that the change from grey to finished will be predictable although the prediction may not be simple as (for a given yarn count and finishing process) there are at least two variables involved, namely the original twist level and the tightness factor of the fabric.
3. The relationship between twist liveliness and loop loading weight is now shown to be strongly non-linear. This is a severe disappointment because it undermines our choice of an arbitrary test load (10 g) for measuring liveliness. It is unthinkable to introduce a routine test method which requires separate evaluations at a series of loads because of the intolerable increase in testing time which would result. Therefore attention must presumably be turned towards a test method which operates at (close to) zero load.
4. In spite of the difficulties twist liveliness is a parameter which may well be predictable from a relatively simple grey yarn test (twist) and may well provide a quantitative estimate of the so-called finishing factor, which would allow rapid calibration of new wet processing routes. For this reason it is worthwhile pursuing these measurements on a wider range of yarns and finished fabrics. The next step presumably is to establish whether a correlation exists between twist liveliness in the yarns taken from finished fabrics and the reference dimensions of those fabrics.

TABLE 1

MEANS OF YARN

	2	4	8	16	33
TF3·5	33.75	40	48.55	63.3	84.5
TF3	25	30.3	39.05	49.8	66.35
TF4	31.55	37.25	45.6	60.2	87.85

95% CL YARN

	2	4	8	16	33	MEAN
TF3·5	1.37	1.68	2.09	1.5	1.28	1.58
TF3	0.79	1.72	2.03	1	1.92	1.49
TF4	2.45	1.92	1.29	1.7	2.27	1,93
MEAN	1.54	1.72	1.80	1.40	1.82	$\bar{x}$ = 1.67 σ = 0.47

% ACC. YARN

	2	4	8	16	33
TF3·5	3.52	3.63	3.73	2.05	1.32
TF3	2.74	4.92	4.5	1.74	2.5
TF4	6.73	4.46	2.46	2.44	2.24

Table 2

YARN FROM FABRIC - MEAN TURNS PER METRE

Sample	2g	4g	8g	16g	33g	
1	22.55	25.1	34.9	46.9	55.4	3.5
2	21.35	28.25	34.85	50.5	62.7	
3	7.75	13.15	21.9	33.75	46.05	3.0
4	15.9	15.2	26.15	34.2	49.35	
5	25.6	34.35	42.4	53.25	69.3	4.0
6	23.8	35.25	47.15	60.7	72.35	

YARN FROM FABRIC - MEAN TURNS PER METRE 95%CL

Sample	2g	4g	8g	16g	33g	Mean
1	1.44	1.62	1.77	2.26	2.46	1.91
2	1.24	1.73	1.67	2.08	3.83	2.11
3	1.78	4.13	2.72	2	3.55	2.84
4	1.97	1.25	2.85	2.64	2.62	2.27
5	1.37	1.62	2.31	2	4.06	2.27
6	1.34	1.86	2.82	1.91	2.98	2.18
Mean	1.52	2.04	2.36	2.15	3.25	

$\bar{x}$ = 2.26

σ = 0.82

YARN FROM FABRIC - MEAN TURNS PER METRE %Acc.

Sample	2g	4g	8g	16g	33g
1	5.51	5.58	4.39	4.18	3.85
2	5.03	5.31	4.15	3.57	5.29
3	19.88	27.24	10.77	5.14	6.69
4	10.75	7.14	9.43	6.69	4.61
5	4.63	4.08	4.72	3.25	5.07
6	4.88	4.56	5.18	2.73	3.57

Figure 1

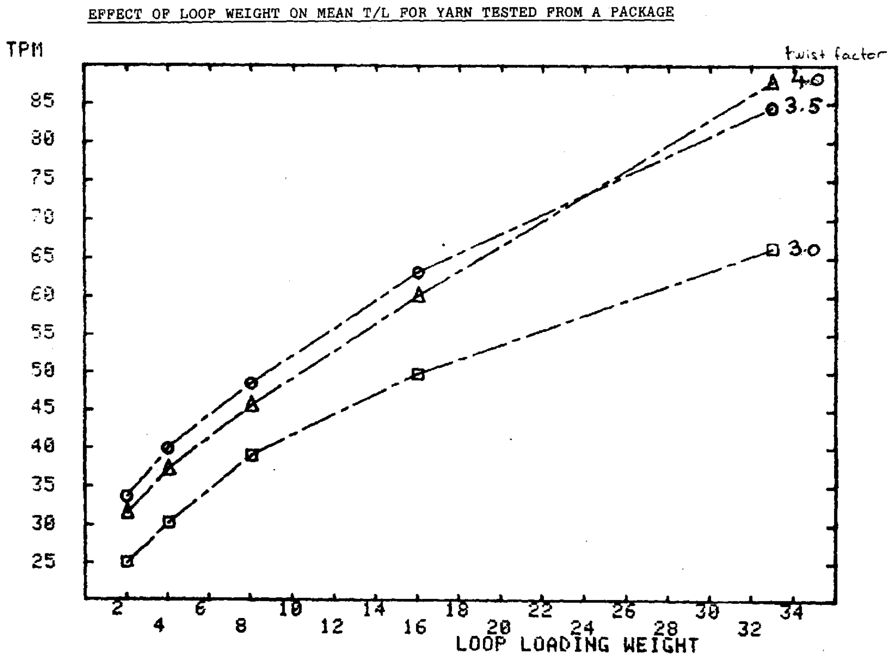


Figure 2

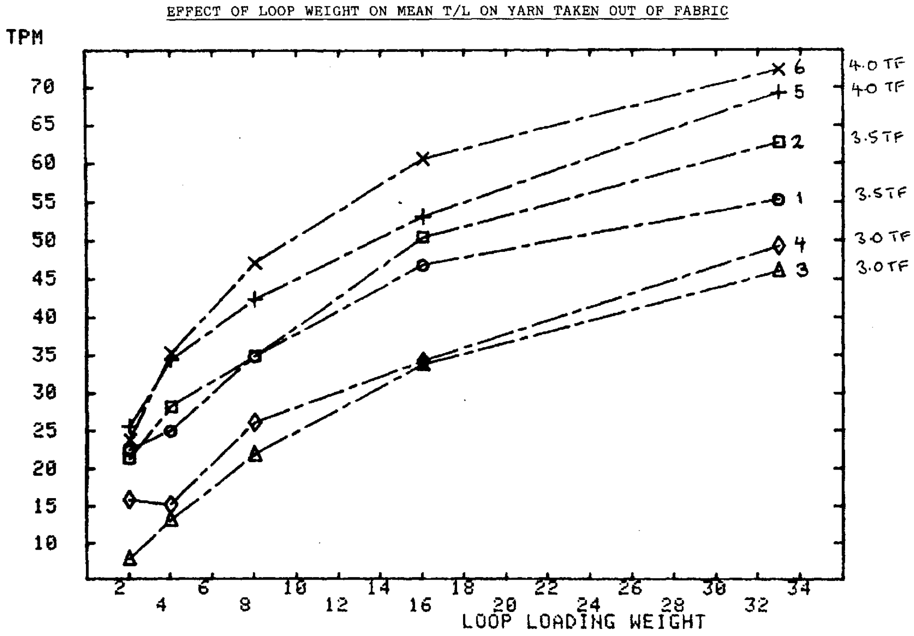


Figure 3

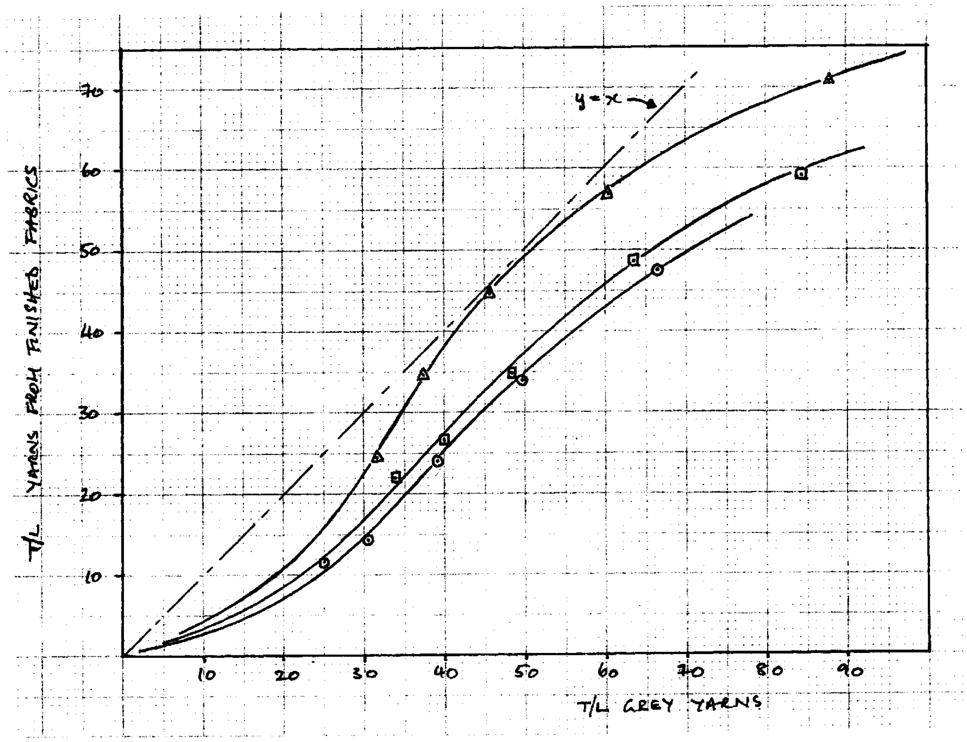


Figure 4

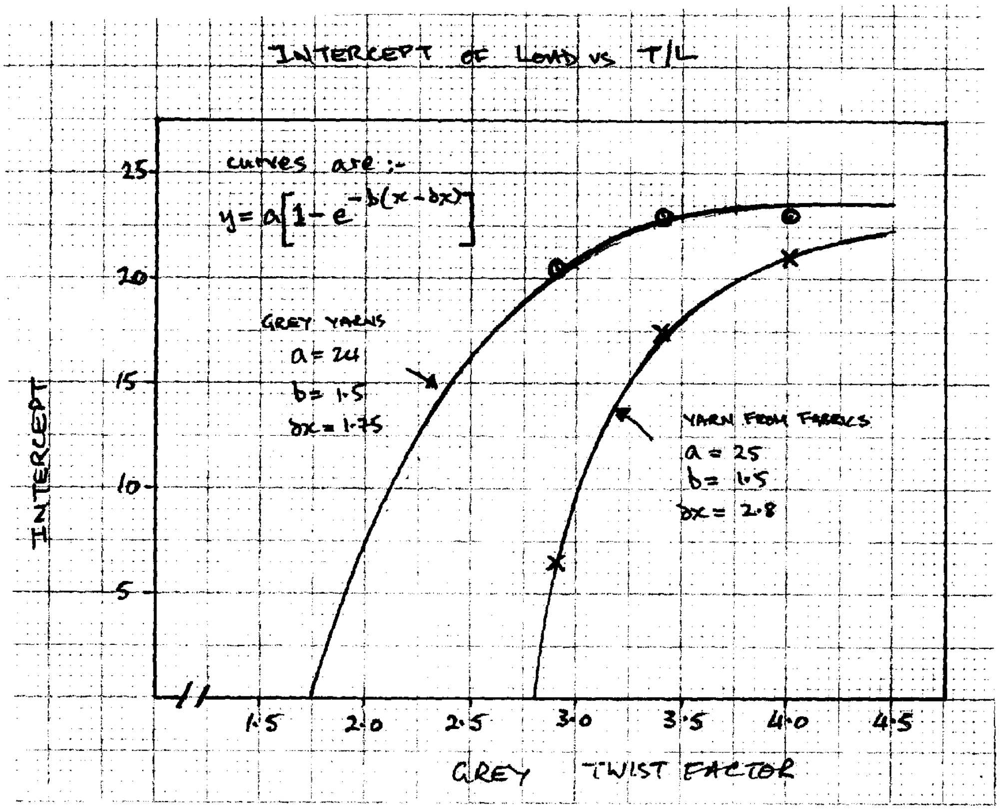
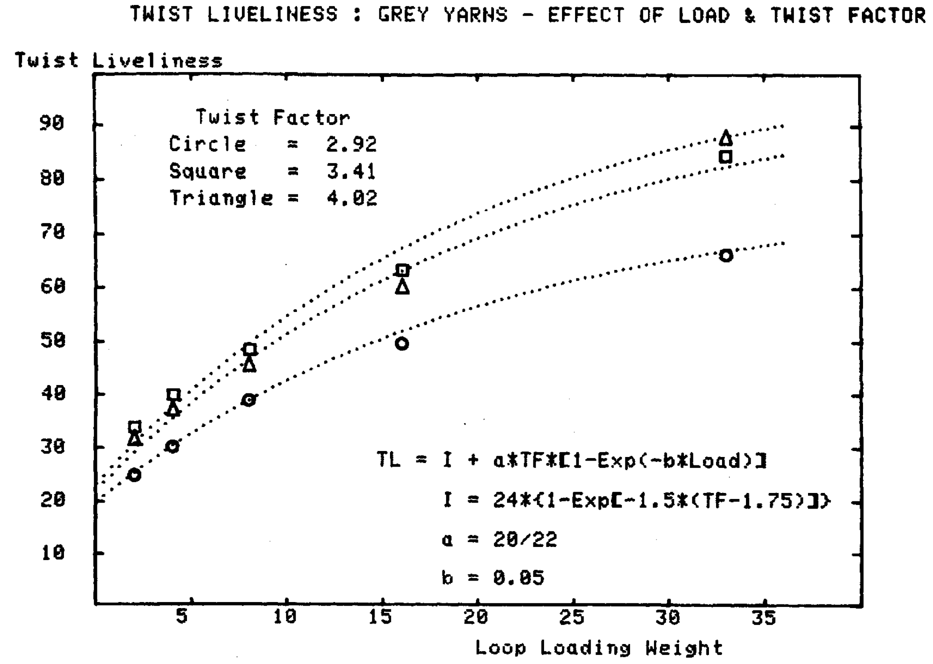


Figure 5



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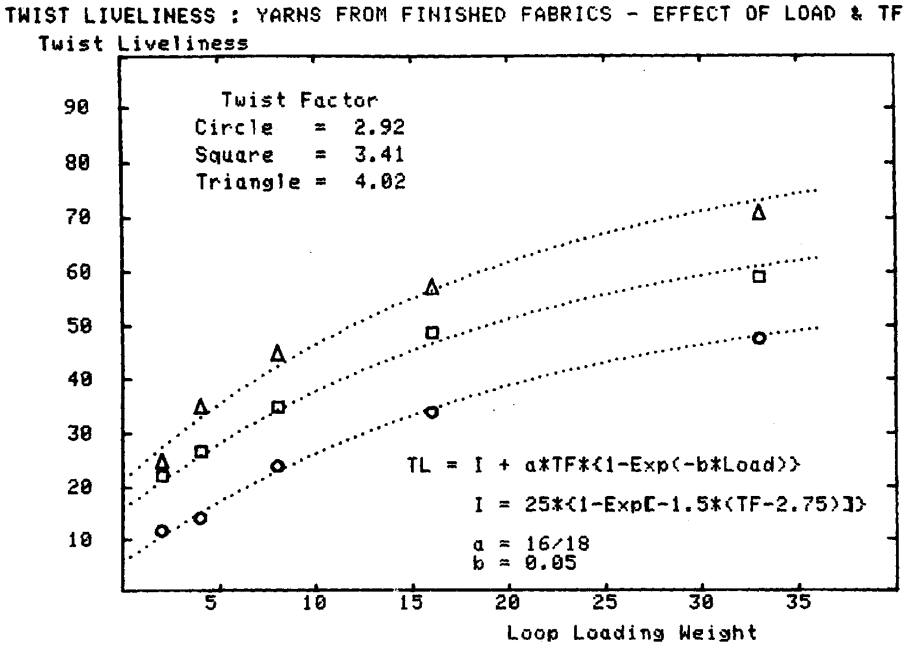

Figure 7

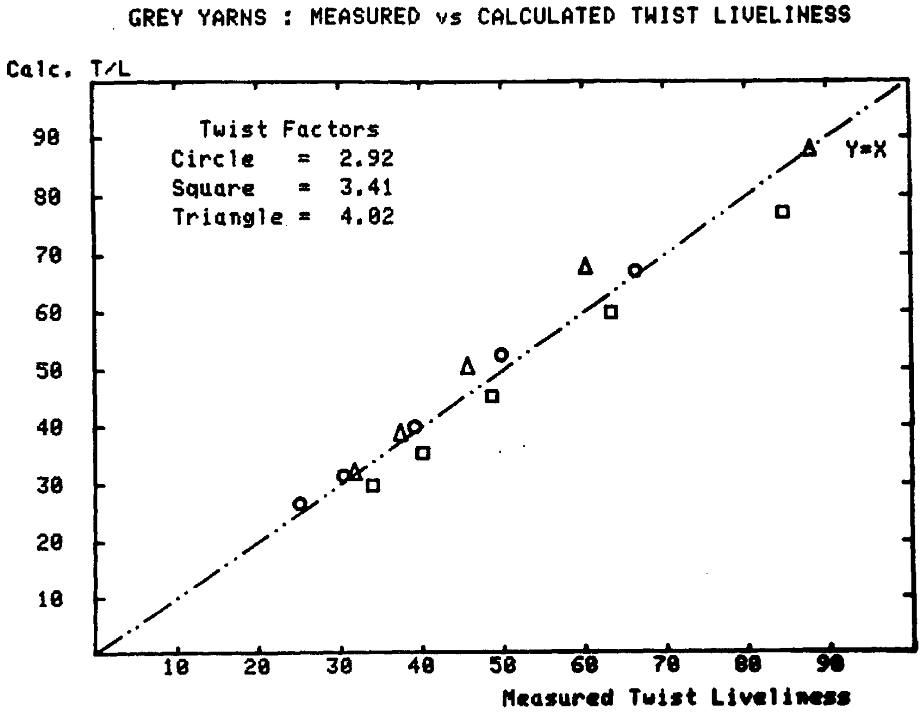
GREY YARNS : MEASURED vs CALCULATED TWIST LIVELINESS

Figure 8

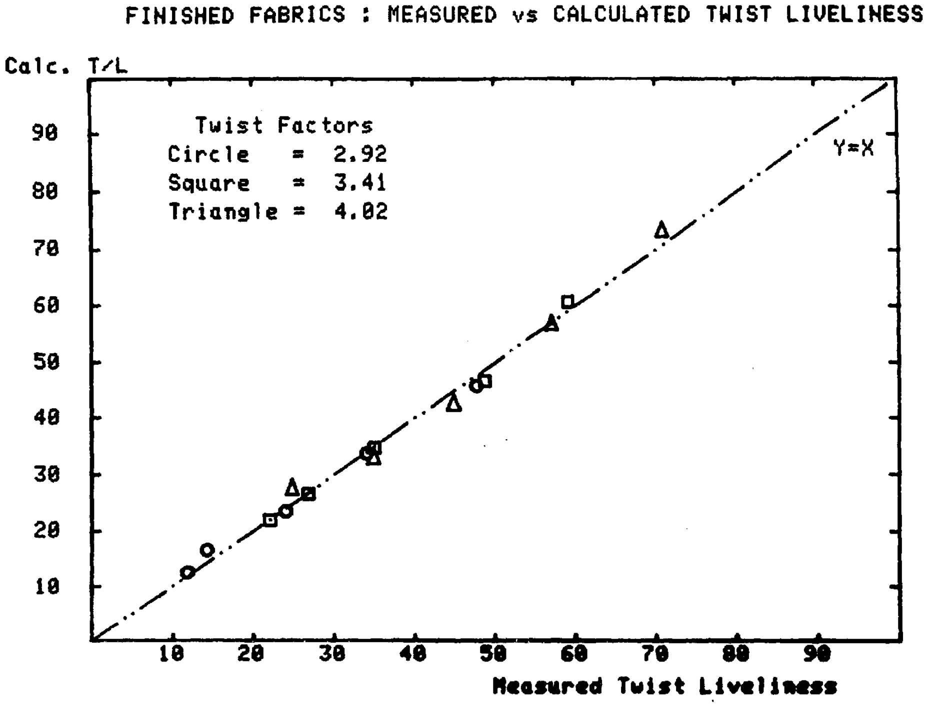
FINISHED FABRICS : MEASURED vs CALCULATED TWIST LIVELINESS

Figure 9

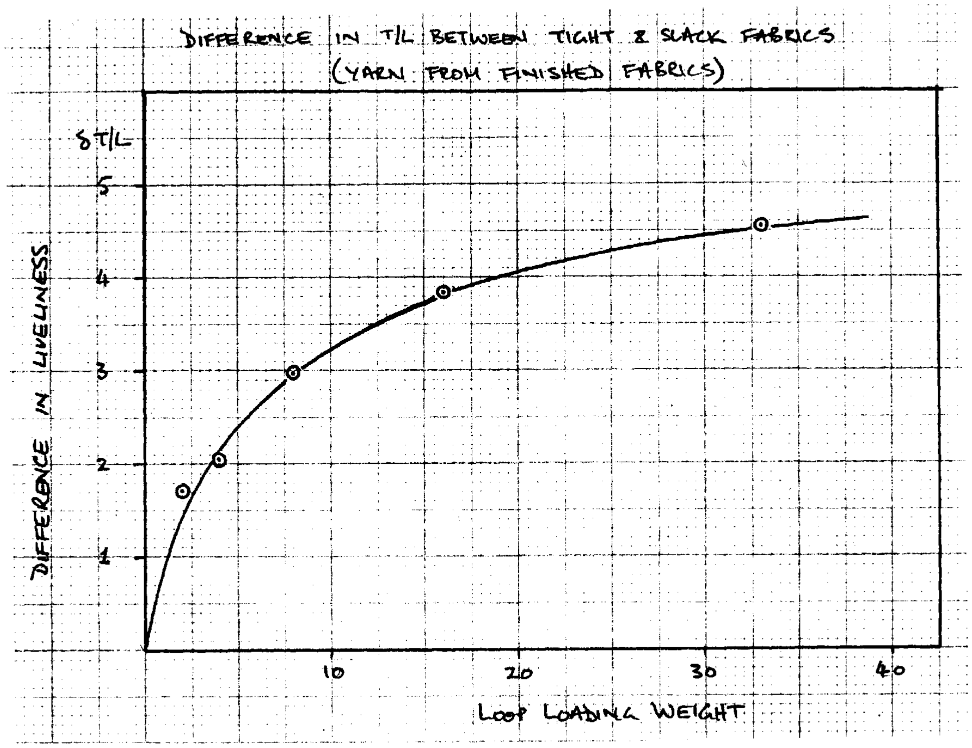

Figure 10