

Mechanical properties of solvent-induced modified polyester yarns

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The strength and elongation properties of flat, high-twist and spun polyester yarns treated with trichloroacetic acid – methylene chloride (TCAMC) have been studied. It is observed that TCAMC causes major changes in the tensile behaviour of yarns. The modified yarns show higher extensibility, lower strength and initial modulus and improved work of rupture. The effect of treatment time on strength, elongation, initial modulus and work of rupture has also been investigated.

Keywords: Flat yarn, High-twist yarn, Initial modulus, Polyester, Spun yarn, Tensile strength, Trichloroacetic acid-methylene chloride, Work of rupture

1 Introduction

Polyester fibres are widely used in the textile sector in the form of flat and texturised filament yarns and staple fibres suitable for blending with other fibres such as cotton, viscose, wool, etc. A wide variety of modified polyester fibres with better properties have been developed to replace the conventional ones for the specific needs of the consumers. Anionic and cationic dyeable polyester fibres have been developed by incorporation of polyamides or sulphonic acid salts during the polymerisation process¹. Flame-retardant fibres have been produced making use of flame-retardant chemicals². Antistatic fibres have been developed by incorporating antistatic agent during or immediately after polymerisation reaction³. Other types of fibres such as carrier-free type, hydrophilic polyester and low-temperature melting fibres have also been developed for specific end uses.

The modification of the internal structure of polyester, either at fibre stage or at yarn stage, is possible by suitable solvent pretreatment (solvent-induced modification) or by thermal means. Both the treatments produce crystallization in the polymer which lowers the glass transition temperature (T_g) and enhances the segmental mobility. The main difference between thermal crystallization and solvent-induced crystallization is that in the former there is no external molecular species involved to crystallize the polymer whereas in the latter the presence of another molecular species is required.

The mechanical properties of any substrate determine its behaviour during processing and also during its use in the form of yarns and fabrics. Since the strength, elongation, deformation and recovery characteristics of textiles are mainly responsible for their usefulness in actual application, a detailed investigation of their mechanical properties is of immense help to the industry. The effect of trichloroacetic acid-methylene chloride (TCAMC) on structural changes in different types of polyester yarn with respect to tensile characteristics are discussed in this paper.

2 Materials and Methods

2.1 Materials

PET [poly(ethylene terephthalate)] yarn samples having the following specifications were selected for this study: Flat yarn (50D/36), high-twist yarn (40 D/27; $2200 \pm 5\%$ TPM); and spun yarn (Ne – 20/1).

Trichloroacetic acid, methylene chloride and acetone, all of LR grade, were used.

2.2 Methods

2.2.1 Pretreatment

Desired concentrations of trichloroacetic acid-methylene chloride (TCAMC) reagent were prepared for pretreatment of yarn samples. The treatment was performed at room temperature (about 30°C) in a specially made trough for differ-

ent durations, keeping the material-to-liquor ratio at 1:100. The treated samples were rinsed with methylene chloride and then with acetone to remove any adhering reagent. Since the evaporation of acetone is high even at room temperature because of its lower boiling point, the treated yarn samples got dried in very short time at room temperature without any need for oven drying. The yarns were conditioned and the tensile test was carried out in an atmosphere of $27 \pm 2^\circ\text{C}$ and $65 \pm 2\%$ RH.

2.2.2 Assessment of Denier

BIS cut and weight method⁴ was used to determine the fineness of yarns.

2.2.3 Tensile Test

An Instron tensile tester (model no.6021) was used for determining the stress-strain behaviour of polyester yarn samples. A gauge length of 50 mm instead of 500 mm as specified in Indian Standards was used since the TCAMC treatment imparts very high elongation ($> 780\%$). The upper movable jaw of the particular instrument would travel a distance of maximum 13% if 500 mm is chosen as test length. The rate of extension was kept at 50 mm/min. The tenacity and extension-at-break were determined from the average value of 30 tests. For each sample, 5 stress-strain curves whose breaking load was close to the mean value were selected and superimposed to get a characteristic curve. The initial modulus, yield point and work of rupture were calculated from the stress-strain curves.

3 Results and Discussion

3.1 Tenacity and Breaking Extension

The changes in the tensile properties of treated yarns (Table 1) show the structural changes due to solvent-induced modification effected by TCAMC. The tensile strength decreases with in-

crease in concentration of TCAMC, irrespective of the sample type. The extent of loss varies from low to medium depending on the type of yarn used. It is least (4%) in high-twist yarn, 10% in spun yarn and about 24% in flat yarn. In contrary to the loss in strength, the elongation of all the treated yarns increases with increase in concentration. The improvement in spun yarn (131-315%) is very high as compared to that in flat yarn (73-139%) and high twist yarn (14-25%).

The changes in tensile properties of TCAMC-treated polyester yarns are due to increase in chain mobility which results in internal structural rearrangement of the polymer chains. This observation is in agreement with the findings of Weigmann and Ribnick⁵. It is the general finding of the researchers^{6,7} that in most cases, solvents do not penetrate into the compact crystalline region in polymers and, therefore, do not affect their strength significantly. It may be seen from Table 1 that the flat yarn suffered a loss in strength of about 24% at higher TCAMC concentration (5%). This indicates that at higher concentration, TCAMC is capable of penetrating into the crystalline region of the polyester after attacking the amorphous region and breaks down the polymer chains, resulting in significant strength loss. Beyond 5% concentration, it is expected that TCAMC not only disorients the crystallinity but also breaks the various secondary forces present in the polymer and facilitates disintegration.

The increase in elongation of polyester yarns, irrespective of their nature, observed due to TCAMC treatment is explained by the assumption that TCAMC produces some measure of freedom for molecular movements in the polymer by relaxing the various lateral forces such as covalent bonds, hydrogen bonds and van der Waals' forces which are responsible for holding the chain molecules inside the polymer. Because of this flexibility of the chain molecules, higher extensibility of the treated yarns resulted. The degree of

Table I—Tensile properties of polyester yarns

Per cent concentration of TCAMC (w/v)	Flat yarn		High-twist yarn		Spun yarn	
	Tenacity g/den	Elongation %	Tenacity g/den	Elongation %	Tenacity g/tex	Elongation %
0	4.12	35.2	2.85	38.3	25.85	13.5
1	3.57	61.0	2.83	43.5	25.60	31.2
2	3.49	63.8	2.81	46.6	25.47	36.6
3	3.40	66.7	2.80	47.0	25.18	42.0
4	3.35	75.2	2.78	47.6	23.82	49.1
5	3.15	84.2	2.73	47.9	23.33	56.0

molecular relaxation progressively increases with the increase in concentration of TCAMC (Table 1).

3.2 Effect of Treatment Time on Strength

To observe the rate of interaction of TCAMC with PET polymer at lower concentration and time, the spun yarn samples were treated with very low concentrations (0.5% and 1%) of TCAMC for 2, 4 and 5 min. and their tenacity values recorded. The bar chart (Fig.1) confirms that TCAMC is able to penetrate into the PET matrix even at lower concentration. This reveals the high interacting power of TCAMC and affirms that the solubility parameter value of this reagent is very close to the solubility parameter value of PET. It may be recalled⁸⁻¹⁰ that the interacting power of the solvent and polymer depends on the closeness of their solubility parameter values. Since the interacting power of the TCAMC reagent and PET polymer is very high, maximum changes in the polymer matrix take place in very short time and further increase in treatment time has no significant effect on loss in strength, as evidenced by the results shown in Fig.2. The tenacity of the flat yarns treated with 5% TCAMC for different durations is more or less same.

3.3 Effect of Treatment Time on Elongation

To see the effect of treatment time on elonga-

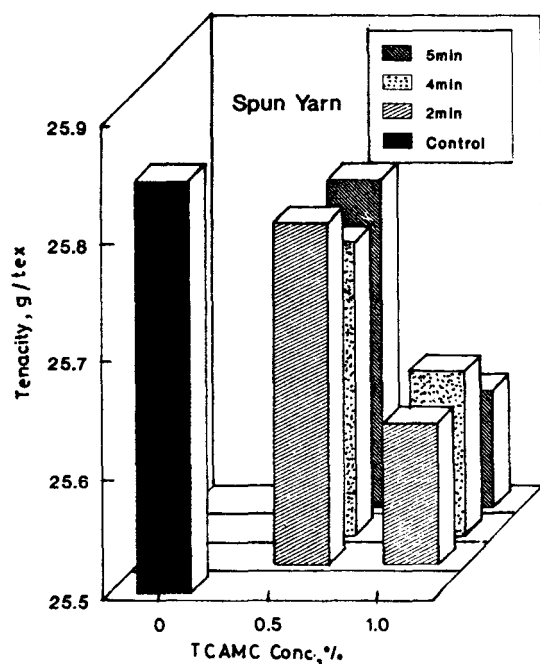


Fig. 1—Effect of lower TCAMC concentration and treatment time on strength of spun polyester yarn

tion, the flat yarns were treated with 5% TCAMC for different durations and the results are shown in Fig.3. It is observed that elongation increases with the increase in treatment time up to 10 min and then it decreases with further increase in treatment time. From this, it is understandable that the chain molecules after attaining the maximum relaxation from the holding power of the lateral forces tend to deteriorate slowly and as a result, higher strength loss (Table 1) and decrease in elongation are observed.

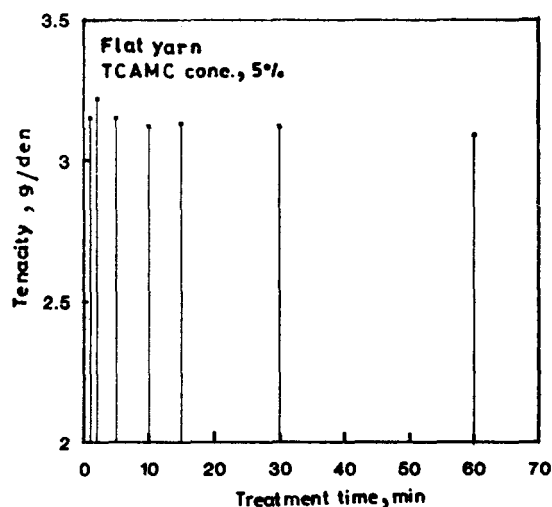


Fig. 2—Effect of treatment time on strength of flat polyester yarn

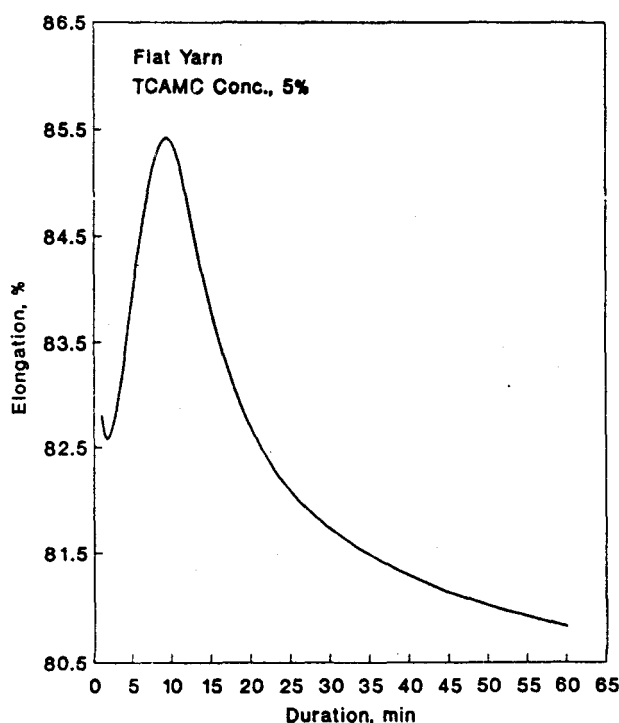


Fig. 3—Effect of treatment time on elongation of flat polyester yarn

To observe the effect of TCAMC at lower concentration and treatment time on elongation, the spun yarns were treated with 0.5% and 1% TCAMC for 2, 4 and 5 min. The treated yarn showed significant increase in elongation (Fig.4) without compromising strength (Fig.1). This observation once again reaffirms the high interacting power of TCAMC with PET even treatment at room temperature.

3.4 Changes in Initial Modulus

The initial modulus of the treated yarns decreases with the increase in TCAMC concentration (Fig.5). The decrease in the case of flat yarn is high even at low concentration (1%) and treatments with higher concentration have no significant influence on the % decrease. The drop observed in high-twist yarn is more or less linear with the treatment concentration. In spun yarn, the trend observed is same as in flat yarn but the modulus decreased by 50% only at extreme treatment level. The decrease in modulus of the treated yarns is perhaps due to the plasticisation effect imparted in the polymer by the TCAMC treatment.

The variation in initial modulus due to treatment time at a given concentration level was assessed by treating the flat yarn sample with 1-5% TCAMC for different durations (1-5 min). The treatment duration was extended up to 60 min for

extreme level of treatment. The results (Fig.6) show that the drop in modulus due to treatment time is not significantly high. This shows that the maximum plasticisation occurred in very short treatment time.

3.5 Changes in Work of Rupture

Fig.7 shows the work of rupture, which is a measure of toughness and wear life of the modifi-

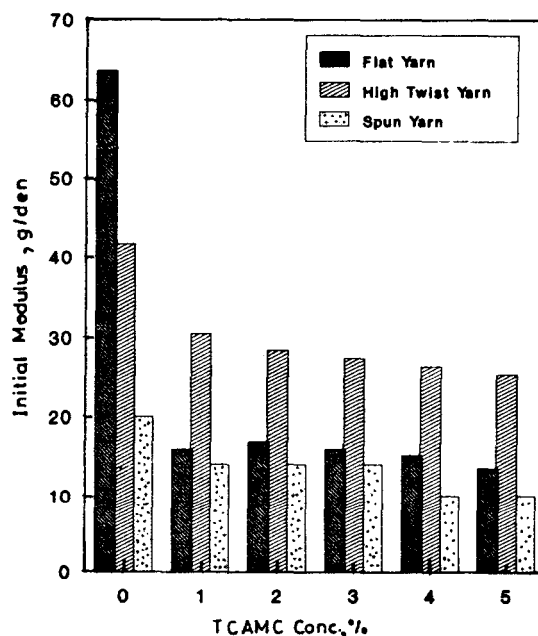


Fig. 5—Effect of TCAMC concentration on initial modulus of different polyester yarns

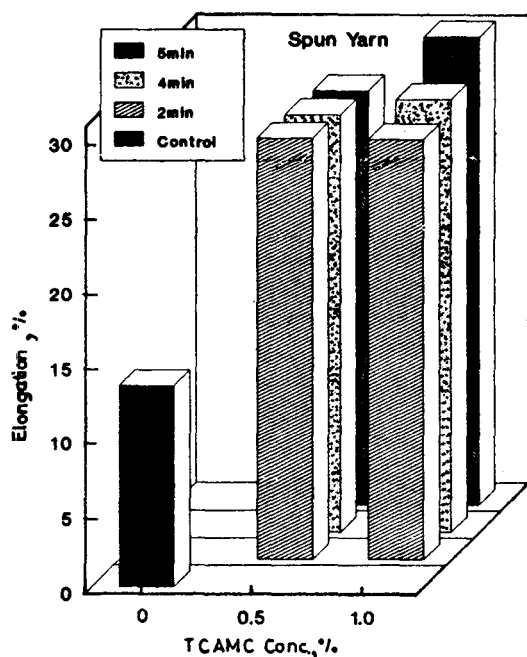


Fig. 4—Effect of lower TCAMC concentration and treatment time on elongation of spun polyester yarn

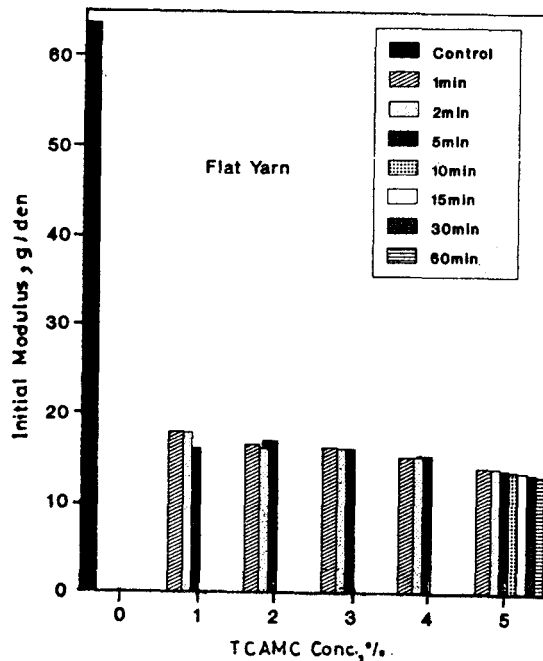


Fig. 6—Variation in initial modulus of flat polyester yarn with TCAMC concentration and treatment time

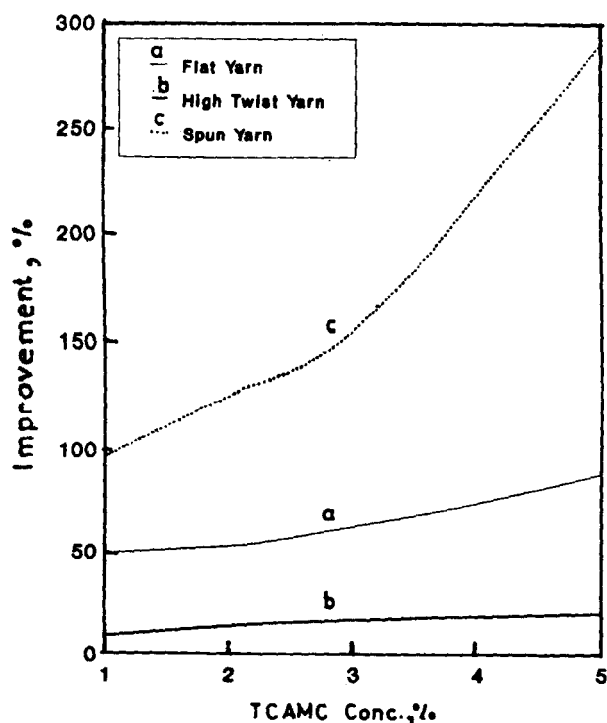


Fig. 7—Per cent improvement in work of rupture of treated polyester yarns

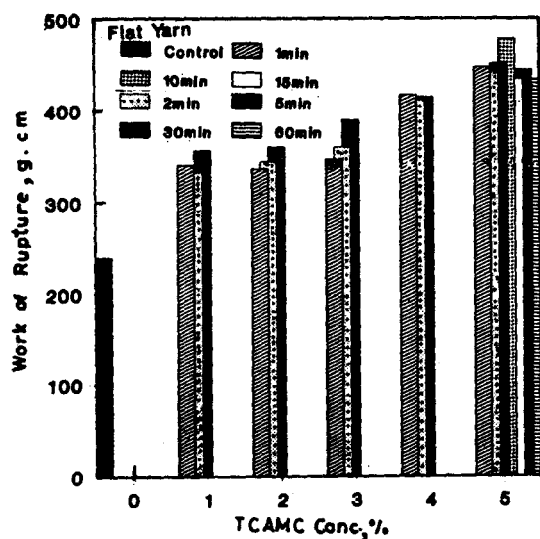


Fig. 8—Effect of TCAMC concentration and treatment time on work of rupture

ed polyester yarns. It shows that spun yarn samples possess higher work of rupture than the other two types of yarns. While significant improvement is observed in toughness of flat yarn at extreme treatment level, no appreciable improvement is seen in the case of high-twist yarn. This trend may be correlated with the elongation property of treated yarns since the work of rupture is proportional to the elongation behaviour of yarns.

It is also observed that the treatment time does not influence the work of rupture, even 60 min duration at extreme treatment level (Fig.8).

4 Conclusions

4.1 Strong interaction between TCAMC and polyester yarn is observed at room temperature treatment. The interacting power of the reagent is high even at very low concentration and short duration treatment.

4.2 The high interacting power of TCAMC with the PET type polyester shows that the solubility parameter value of this reagent is close to that of PET.

4.3 TCAMC treatment decreases the tenacity and increases the elongation of polyester yarns. The extent of variation in increase in elongation and decrease in strength depends on the nature of polyester yarns used, concentration of TCAMC and the treatment duration.

4.4 The changes in initial modulus show that the structural changes effected in polyester yarn by TCAMC. The initial modulus reflects the solvent effects on intermolecular bonding within the fibre structure.

4.5 The higher improvement in work of rupture of treated yarn is an another noteworthy feature observed.

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