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A STUDY ON THE PLIED COTTON RING SPUN YARN TENACITY

دراسة متانة الخيوط المزوية من خيوط الغزل الحلقى القطنية

By

Assoc. Prof. *I. M. Rakha*

الخلاصة :

يقدم هذا البحث معادلة جديدة لحساب متانة الخيوط المزوية المنتجة من خيوط الغزل الحلقى القطنى. وتشمل الدراسة تأثير خواص الشعيرات وأس البرم للمفرد والمزوى وعدد الخيوط المزوية وكذلك جودة الغزل (مسرح - ممشط). وتشير نتائج البحث الى أن هناك توافق بين النتائج العملية والنتائج المحسوبة بالمعادلة المقترحة لحساب متانة الخيوط المزوية.

Abstract :

This work presents an emperical formula of plied yarn strength produced from ring spun cotton yarns. Experiments carried out on several samples of cotton fibres and the investigation concerned with the influence of fibre properties, single twist, ply twist and number of plies and spinning quality.

The results obtained with this formula agree satisfactorily with the experimental data.

(1) Introduction :

The strength of plied staple yarns vary complicatedly according to the fibre properties, number of plies, twist directions and single and ply twist multipliers.

Experimental studies on this subject has been carried out /1,2,3,4,5,6,8/ but not considered enough investigation from the point of view of analytical treatment. On the other hand there are many analytical researchers /2,7,9,10,11,12,13,14,15,/ but the proposed equation deduced for predicting the strength of plied staple yarns is not accurate enough because there are no equation taking into consideration all the factors affecting plied yarn strength.

The aim of the present study is predicting a formula for determination the strength of plied cotton yarns considering the following parameters : fiber parameters such as : "Fibre strength, length and fineness", single, ply yarn twist, number of plies and twist diction.

(2) Theoretical analysis :

The literature suggested that yarn tensile properties were affected by several parameters such as fibre strength, strength irregularity, percentage of broken fibres and yarn twist. What follows is a trial modifying these facts. The determination of plied yarn strength it is important to consider that following parameters :

1) The effect of plied yarn strength irregularity :

From the theory of folding, it is known the yarn irregularity of cross section and consequently the strength irregularity decreases as the number of plies increases, and theoretically the following formula can be used.

$$V = \frac{100}{\sqrt{m_0 \quad m_1}} = \frac{\sigma}{\bar{p}} 100 \approx 1.25U \qquad (1)$$

Where : V : Coefficient of variation of yarn strength.

mo : Number of fibres in single yarn cross-section.

m_1 : Number of plies.

σ : The standard deviation of strength.

$\bar{p}$: The average strength of the yarn.

U : Linear irregularity of single yarn strength /6/, and equal to

$$= U_0 + \frac{65}{\sqrt{m_0}} \qquad (2)$$

Where : U_0 = Coefficient depends on the spinning quality and equal to : 3 for combed yarns and 4.5 for carded yarns.

By combining equations (1) and (2) we obtain :

$$U_1 = \frac{U_0}{\sqrt{m_1}} + \frac{65}{\sqrt{m_0 m_1}} \qquad (3)$$

It is also known that the yarn breakage at very week points, and consequently the regarding value of tensile tester can be calculated as follows :

$$p = \bar{p} - 3\sigma \qquad (4)$$

Where : P : tensile strength reading.

By substituting eq. (1) and (3) in (4), we obtain :

$$p = \bar{p}(1 - \frac{0.0375}{\sqrt{m_1}} U_0 - \frac{2.44}{\sqrt{m_0 \quad m_1}}) \qquad (5)$$

The term between brackets defined physically as the uniformity coefficient of plied yarn strength.

The experimental results of strength irregularity of plied yarns and those calculated by formula (3) are shown in table (4).

(2) The percentage of broken fibres :

From the earlier studies /7,9,16/ concerned with the behavior of spun yarns during breakage and the mechanics of strength of the plied yarn it was found that the pressure along the fibre in spun yarns increases from zero to the value determined by the yarn extension and then decreased to zero at the other end. If we assume that the frictional force which prevents fibre slippage created on a length of fibre equal l_{sl}, thus the fibres presents in the yarn and firmly gripped with the meighbours fibres at length longer than l_{sl} will break and the other fibres which has a contact length less than l_{sl} will be subjected to slippage. Thus the percentage of broken fibres which contributed in the yarn strength are equal to

$$\left(1-\frac{2L_{sl.}}{L_{st.}}\right) \quad /17/$$

Where : $l_{st.}$: Staple length of fibres.

Also from the theoretical assumptions given by Varasheelaf 11 it is found that; the forces acting on the fibre element of the yarn as shown in Fig. (1) represented by the following relation :

$$dN = 2Y \sin\frac{d\phi}{2} - dy \sin\frac{d\phi}{2} + \rho\,\sigma\,d\phi \qquad (6)$$

Where : dN : The reaction on the fibre element.

Y : The tension on the fibre element.

ρ : The radius of twist curvature of the plain in which the fibre lies.

σ : The stress from the outer layers on the unit length.

It was considered that sin dϕ = dϕ and the small values are negligent. Equation (6) can be rewritten as follows :

$$dN = Y\,d\phi + \rho\,\sigma\,d\phi$$

Also the value of dy taken from the projection of the tangent as follows :

$$dy = f\,d\,n + H\,\rho\,d\phi \qquad (7)$$

Where : H = Fibre griping force.

f = Coefficient of friction between fibres.

Equation (7) can be applied for plied yarn by neglecting H, and equal to

$$dy = f\,d\,N$$

From equations (6) and (7) we can get :

$$d\phi = \frac{dy}{FY + F\rho\,\sigma} \qquad (8)$$

By integrating dϕ

$$\phi_{sl} = \int_0^y d = \int_0^y \frac{dy}{fy + f} = \frac{1}{f} \ln \frac{fy + f}{f} \qquad (9)$$

Where : $Y = P_f$: Fibre breaking load.

$$\phi_{sl.} = \int_0^{L_{sl}} \frac{dt}{\rho} = \frac{L_{sl.}}{\rho} \qquad (10)$$

$$\rho = \frac{r}{\sin^2 \beta} = \text{const.} \qquad (11)$$

r : Yarn radius.

β : Twisting angle.

From the previous equations (9), (10) and (11), we can get :

$$L_{sl.} = \phi_{sl}\rho = \frac{\rho}{f} \ln \left(1 + \frac{P_f}{\rho\,\sigma}\right) \qquad (12)$$

Where : $\sigma : P_f/2\rho$ from varsheelaf /11/

since the twist spiral radius is not actually equal to the yarn radius as stated in the previous work /18/$d_s = 0.8$ d.

Where : d_s : The diameter of twist spiral.

d : The actual yarn diameter.

Consequently, it is recommended to take $\sigma = \frac{P_f}{1.6}$ (13)

$$L_{sl.} = \frac{\rho}{f} \ln 2.6 = \frac{0.5 \ d_s}{F \ \sin^2 \beta} = \frac{0.4 \ d}{F \ \sin^2 \beta} \qquad (14)$$

Where : $F = 0.25 - \frac{0.006 \ p_f}{\rho}$ (15) varasheelf /11/, and

$F = \frac{2}{2 + \sqrt{N}}$ (16) sakaloof /21/

Where : N : is the metric yarn count.

The coefficient of friction "f" between fibres is not constant. In relation with twist it is linearly proportional with "α_T" as given by the following relation /19/

$$F = \frac{\alpha_T.10^{-2}}{\sqrt{\alpha_T.10^{-2}} + 30} \qquad (17)$$

Where : α_T : is the twist multiplier of plied yarn and equal to

$$\alpha_T = \tau_p(\alpha_s 10^{-4} \ / (0.8)^{ml \ 10} \qquad (18)$$

d_p :is the plied yarn diameter and equal to : d_s, C (19)

Where : C : Constant depends on the number of plies, the value C recommended by sakaloof /21/ is given in table (3).

ml	2	3	4	5	6
C	1.8	2.2	2.56	2.86	3.13

β : is the twisting angle and equal to $\tan^{-1} \pi d_p \tau_p$

Where : τ_p : Turns per meter of plied yarn.

It is roughly known that the mean yarn strength p equal to

$$P_f . m_0 m_1 (1 - \frac{2L_{sl.}}{L_{st.}}) x \qquad (20)$$

Where x : is the twist correction factor.

By combining equation (20) and (5) we can get :

$$P = P_f m_0 m_1 (1 - 0.0375 \frac{U_0}{\sqrt{m_1}} - \frac{2.44}{\sqrt{m_0 m_1}})(1 - \frac{2L_{sl.}}{L_{st.}}) x \qquad (21)$$

(3) The twist correction factor :

In case of single yarns it is easy to take the correction factor equal to 1 when the yarn twist factor reaches its optimum value, and then decreases according to the difference between the optimum and actual twist factors. But in case of plied yarn the problem becomes more complicated, because there are three factors must be taken into account, these are (α_s) single twist factor, (m_1) number of plies and ply twist factor (α_p).

$$\text{Thus} \quad X_1 = 2.55 \left(\frac{m_1}{\alpha_s}\right)^{0.14} \qquad (22)$$

According to the nature of strength, twist curves for different number of plies the value m_1 corresponding six plies is equal to 2.5.

While the value of twist correction factor X_2, as shown in table (3), depends on the difference between the actual twist factor and optimum twist factor /20/

Thus equation (21) can be rewritten as follows :

$$P = P_f \; m_0 m_1 \left(\frac{1 - 0.0375}{\sqrt{m1}} - \frac{2.44}{\sqrt{m_0 m_1}} \right) \left(1 - \frac{2L_{sl.}}{L_{st}} \right) x_1 x_2 \qquad (23)$$

(3) Experimental work :

To verify the plied strength predicted from the formula deduced in the present work, a sample of soviet cottons were selected to reduce single ring spun yarns having different linear densities at different levels of twist factors.

These yarns plied in S direction with different number f plies ranges from 2 to 6 at different twist multipliers.

A controlled sample from Egyptian cotton G-77 was spun into single and plied yarns.

The fibre properties are shown in table (1) and the plied yarns produced shown in table (4).

The fibre properties are shown in table (1) and the plied yarns produced shown in table (4).

The produced yarns were tested for strength characteristics, strength (gm/tex), C.V% of strength, yarn twist and yarn linear density.

(4) Results and Discussions :

From the experimental results shows in table (4), it is clear that, the strength of plied yarn increases as the number of plies increases from 2 to 5 and then decreases as the number of plies increases. This can be attributed to the components arrangement imply yarn cross-section, because single components taking a pipe form in regular pattern and permits equal pressure in each component and results in a higher strength of plied yarn. On the other hand, with higher number of plies one or more components tend to be in the yarn core while the others wrapping around them. This situation causes non regular pressure in the components and consequently reduces plied yarn strength. Also the plied yarn strength was affected by the amount of single and ply twist and twist directions. The results shows a higher strength for plied yarn produced from single with lower initial twist than those obtained with higher single twist.

This was explained by the increment in the pressure generated by ply twist which over comes the decrement in single pressure as a result of untwisting it with small values for yarns having small twist in singles, and consequently such yarns introduced high pressure values reaches the optimum, strength values. But in case of single yarns with a high ply twist multiplier the decrement in pressure coming from the decrease in single twist which exceeds an increase by ply twist, and strength increases, the increase in pressure by ply twist gradually assumes large proportions and eventually rises above critical level. The experimental results is in agreement with the earlier studies /1,2,3,4,5,6,8/.

The experimental results were compared to calculated values of plied yarn strength for all tested cotton samples.

As shown in table (4) and Fig. (2), which represents the results of the Egyptian cotton sample, there is a slight difference between the actual and predicted values of plied yarn strength.

A computer programs was developed to fit the experimental data of equation (23).

(5) Example of calculation :

In order to produce a sewing threads of 70/3 Ne from Egyptian cotton sample No. (3), (Table 1)

A single yarn of 8.4 tex (70 Ne) were spun at twist factor equal 0.8

$\alpha_{s_{cr}} = 3400 * 0.8 = 2720\ \alpha_{T_t}$ / 22 /

By substituting in $(1 - 0.0375\frac{U_0}{\sqrt{m_1}} - \frac{2.44}{\sqrt{m_0 m_1}})$, where m_1=3, U_0=3 (combed) and m_0 = 69.4 fibres, thus the value between brackets equal : 0.77.

$$L_{sl.} = \frac{0.4\ d}{\sin^2 B}$$ where ; $d = d_s C$, C=2.2 (from table "2")

and $d_s = 0.0819 \frac{T_s^{1.18}}{(\alpha_s 10^{-2})^{0.54}} = 0.118$mm / 18/.

$\beta = \tan^{-1} \pi.d\ \tau_{cr}$, where τ_{cr} is the critical T.P.M. of plied yarn corresponding critical twist factor of plied yarn which equal :

3660 α_T, then by substituting in equation (18) we can get τ_{cr} = 1294 T.P.M. and $F = 36.6 / \sqrt{36.3} + 30 = 0.20$

Thus $\left(1 - \frac{2L_{sl}}{L_{st}}\right) = \left(\frac{1.96}{36.5}\right) = 0.95$

* The correction factor of twist

$$x_1 = 2.55\ (\frac{m_1}{\alpha_s})^{0.14} = 2.55\ (\frac{3}{2720})^{1.44} = 0.98$$

* The correction factor of twist $X_2 = 1\ (\alpha_{cr})$.

* From table (1) : P_f = 4.8 gm and l_{st} = 36.5 mm.

* By substitution in equation (23), we can get :

P = 4.8 * 69.4 * 3 * 0.77 * 0.95 * 0.98 = 716.4 gm = 28.4 g/tex.

(6) Conclusions :

The study of plied yarn strength characteristics gives the following conclusions :

(1) The study affords a formula to predict the strength of cotton plied yarns.

(2) The suggested formula clearly show, the plied yarn strength dependent on fibre properties, single and ply twist, number of plies and spinning quality.

(3) The calculated values deduced from the suggested formula agree satisfactorily with the experimental results.

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Table (1) : Physical and Mechanical properties of cotton fibres

Staple length mm	**Linear density** tex	**Breaking load** gm	**Tenacity** gm/tex	**Single count produced** tex
32.7	0.183	4.2	22.95	25 (carded)
40.2	0.135	4.4	32.59	10, 12, 15 (combed)
36.5	0.121	4.8	39.7	12 (combed)

Table (3) : The correction twist factor X_2

$\alpha_T-\alpha_{cr}$	-1660	-1380	-1100	-830	-550	-280	-140	0	140
X_2	0.8	0.835	0.87	0.9	0.935	0.97	0.985	1	0.98
$\alpha_T-\alpha_{cr}$	370	740	1110	1480	1860	2200	2600	3000	3340
X_2	0.965	0.93	0.895	0.865	0.83	0.8	0.765	0.73	0.7

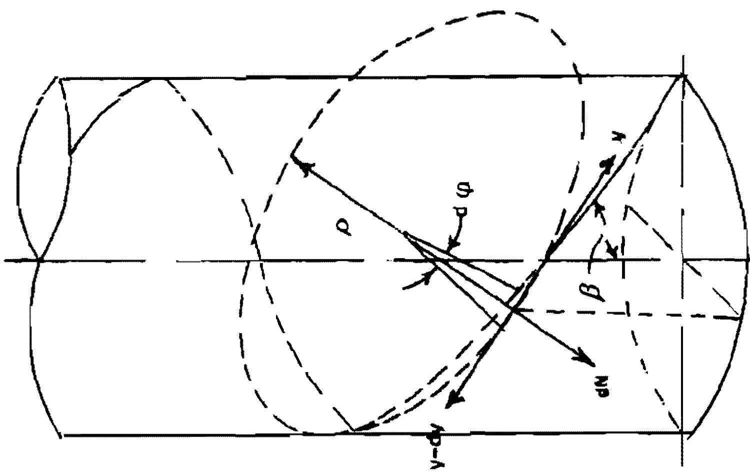

Fig. (1) The forces acting on the fibre element on the yarn

Table (4-a)

Yarn count (tex)	Single twist factor	ply twist factor	Exp. tenocity g/tex	cal. tenacity g/tex	Exp. U%	Cal. U%	Yarn count tex	Single twist factor	ply twist factor	Exp. tenacity g/tex	cal. tenacity g/tex	Exp. U%	Cal. U%
9.9 x 2	3101	1940	16.0	14.6	7.8	7.5	12 43 x 3	3779	2606	19 7	17.0	5.8	5 65
		2291	17.3	16.0					3318	21.5	20.4		
		3003	18 9	18.5					4002	21 6	21.7		
		3559	19.6	20 2					4513	21.0	20.7		
		3902	19.0	19 9					5161	20.5	19.8		
9.9 x 3	3101	2610	17.3	18.9	6.3	6.1	12.43 x 4	3779	2745	19.8	19.1	5.1	4 9
		2923	18 1	20 2					3493	22.6	22.7		
		3308	19.7	21.0					3904	22 7	23.0		
		4064	19.8	22.2					4259	22.0	21.6		
		4642	18.1	21.2					5568	20.6	20.0		
9.9 x 4	3101	2469	20 0	19.1	5 2	5.3	12 43 x 5	3779	2548	20.0	17 8	4.2	4.4
		2653	21.6	22.1					3177	22 4	21 8		
		3130	21 7	24.1					3624	23.1	23.9		
		3677	21.9	24.3					4265	22 6	22.8		
		4253	20.9	23.2					5271	21 5	21.4		
9 9 x 5	3101	2682	22 5	20.2	4.9	4.7	12.43 x 6	3779	2884	20 0	17.7	3.9	4.0
		3160	22.9	22.2					3276	20.3	20 2		
		3678	23.1	24.5					4142	20.1	21.2		
		4181	21.5	23.4					4815	19.5	20.7		
		4650	20 0	22.5					6937	18.8	16.8		
9 9 x 6	3101	2686	20 4	18.9	4.2	4.3							
		3048	20.6	20 6			11.65 x 2	2980	2024	20.3	18.4	7.1	6.8
		3555	20.9	22.8					2651	20.5	21.5		
		4135	20.0	22.7					3179	24 1	23.8		
		4597	19.4	21.8					3805	23.4	25 3		
							11.65 x 3	2980	2029	24 4	19.3	5 8	5.6
									2784	26 9	24 3		
									4013	27.2	27 6		
									4650	26 0	26.3		

Table (4-b)

Yarn count (tex)	Single twist factor	ply twist factor	Exp. tenocity g/tex	cal. tenacity g/tex	Exp. U%	Cal. U%	Yarn count tex	Single twist factor	ply twist factor	Exp. tenacity g/tex	cal. tenacity g/tex	Exp. U%	Cal. U%
11.65 x 4	2980	2286	24 3	21.8	4.6	4.8	14 93 x 4	3452	2645	21.2	19.1	4.5	4.6
		2957	25.5	26.2					3138	22.4	21.7		
		4930	27.2	27.4					3676	22 9	24.0		
11.65 x 5	2980	2432	25 9	22.3	4.2	4.3			4591	22.5	22.6		
		3070	26 4	26.9					5175	21 8	21.4		
		4467	27 9	28.5			14.93 x 5	3452	2768	22.4	19.5	4.1	4 1
		5768	26 4	25.6					3303	23.4	22.1		
11 65x6	2980	2524	24.7	21.4	4.0	3.9			3871	23.5	23.8		
		3186	26.3	24.1					4514	22.3	22.9		
		4636	24.9	26.6					4595	21.6	21.2		
		5639	23 5	24.5			14.93x6	3452	2664	20.5	18.5	3.7	3.8
14 93x2	3452	2323	18.6	15.8	6.7	6.5			3320	20.8	20.8		
		2831	20.3	18.0					3961	20.4	22.1		
		3572	20.7	20.7					3833	18.9	21.0		
		3784	19.8	20.4					3775	17.6	19.4		
		4602	19.0	19.4									
14 93x3	3452	2311	20.3	16.5	5.5	5.3							
		2805	21.5	19.2									
		3135	21 8	20.6									
		3635	22.5	22 7									
		4492	21 0	21.3									

Table (4-c)

Yarn count (tex)	Single twist factor	ply twist factor	Exp. tenocity g/tex	cal. tenacity g/tex	Exp. U%	Cal. U%	Yarn count tex	Single twist factor	ply twist factor	Exp. tenacity g/tex	cal. tenacity g/tex
25.7x2	2715	2025	11.3	9.5	7.8	7.1	14.82x3	3123	2136	19.5	16.1
		2707	13.5	11.8					2594	21.8	18.7
		3130	14.7	13.1					2968	22.5	20.3
		3546	15.2	14.2					3365	22.7	22.1
		4088	13.2	13.8					3809	23.0	21.9
26.05x2	3354	2337	12.0	9.7					2311	20.3	16.5
		3291	14.3	12.9			14.93x3	3452	2806	21.5	19.2
		3596	14.6	13.5					3135	21.8	20.6
		4180	13.5	13.2					3635	22.5	22.7
		4784	12.6	12.6					3635	22.2	21.6
26.38x2	3791	2605	12.8	10.1					4087	22.2	21.6
		3519	14.3	13.0					4492	21.0	21.3
		4230	14.0	12.9			15.05x3	3916	2533	20.6	17.0
		4610	13.1	12.7					3011	21.0	19.4
		5260	12.3	12.0					3437	21.6	21.1
26.6x2	4352	2863	13.4	10.8					4020	21.5	21.5
		3587	14.2	12.5					4656	20.1	20.4
		4415	13.1	12.4					5097	19.2	19.8
		5249	11.7	11.8			15.12x3	4233	2696	21.0	17.3
		5978	11.1	11.1					3305	21.3	20.1
									3656	21.5	21.5
									4278	21.1	20.7
									4795	19.5	20.0
									5443	18.7	18.9

Table (4-d)

Yarn count (tex)	Single twist factor	ply twist factor	Exp. tenocity g/tex	cal. tenacity g/tex	Yarn count (tex)	single twist factor	ply twist factor	Exp. tenacity g/tex	Cal tenacity g/tex
9.8x3	2767	2272	16.3	17.9	11.45x3	2593	1940	21.1	20.3
		2724	18.0	19.8			2472	23.7	23.9
		3010	20.5	20.6			3560	27.7	28.5
		3726	20.7	22.9			4119	26.1	27.9
		3937	20.3	22.5	11.65x3	2980	2029	24.4	19.3
		4197	19.6	21.9			2784	26.9	24.3
9.9x3	3101	2610	17.3	18.9			4013	27.2	27.6
		2923	18.1	20.2			4650	26.0	26.3
		3308	19.7	21.0	11.75x3	3462	2084	24.0	18.4
		4064	19.8	22.2			3143	27.9	25.1
		4291	19.9	21.3			3875	28.5	27.1
		4642	18.1	21.2			4495	25.3	25.8
10 x 3	3459	2910	18.2	19.3			5189	25.0	24.4
		3364	19.3	21.3			2314	25.7	18.7
		3764	19.5	21.9	11.98x3	3946	3447	27.4	25.5
		4360	18.8	21.0			4116	26.0	25.6
		4701	18.0	20.3			5770	22.8	22.3
		5075	17.3	19.8	12.2x3	4432	2559	24.8	19.6
10.2x3	4287	3422	18.5	20.2			3798	26.4	25.4
		3764	19.0	20.8			4702	25.7	24.2
		4503	18.3	19.9			6347	25.7	21.1
		5259	18.0	18.7					
		5548	17.7	18.3					
		5989	16.7	17.5					

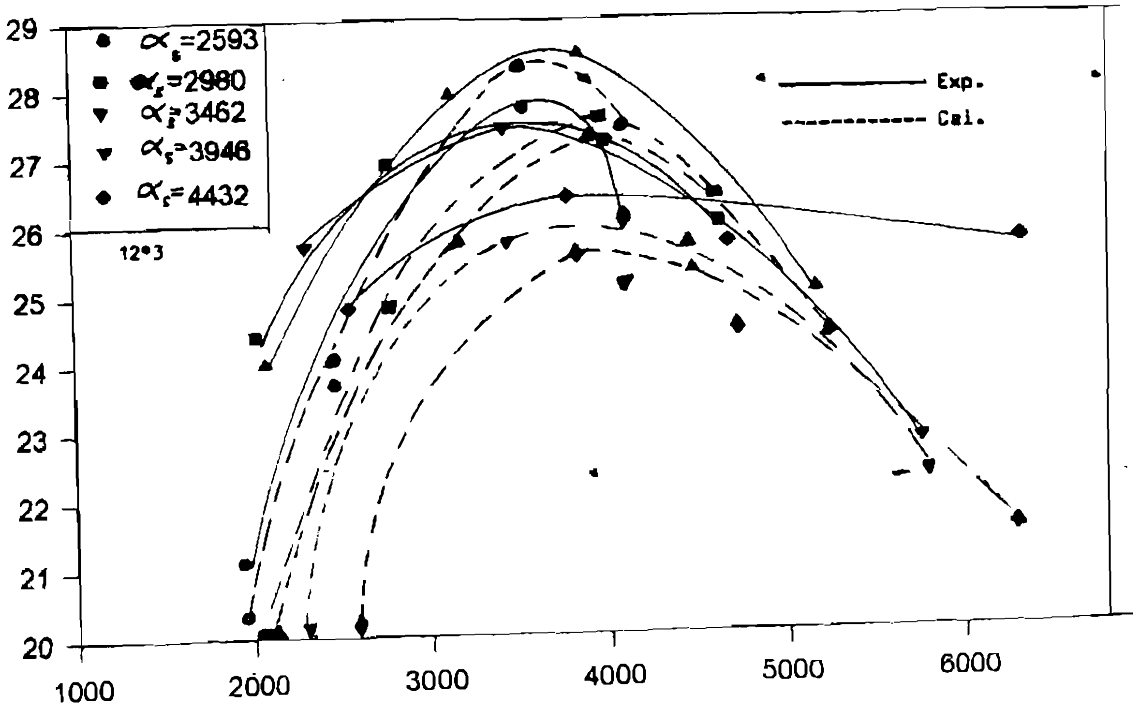

Fig. 2-a $\alpha_T = t\,T^{.8}/\alpha_s 10^{-4})^{.74}/8^{N/10}$

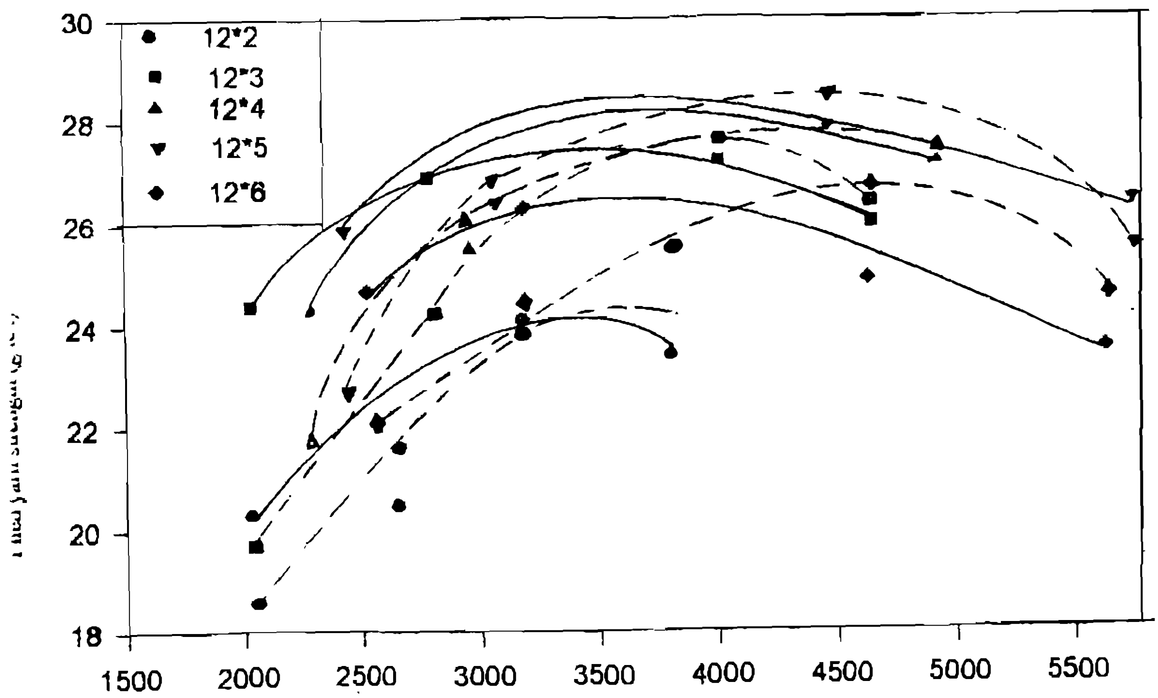

Fig. 2-b $\alpha_T = t.T^{.8}(\alpha_s 10^{-4})^{.74}/.8^{N/10}$