EFFECT OF SURFACE TEXTURE AND INTERFERENCE ON STATICALLY LOADED SHRINK FITTED JOINTS

BY

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ABSTRACT

This paper analyses the effects of interference and surface roughness on the strength of statically loaded shrink fitted joints. In carrying out the experimental work, specimens with different degrees of surface roughness were prepared. Pair of the same degree of roughness but with different amount of interferences were formed. Theoretical model was suggested and imperical equations based on the experimental results were deduced.

NOMENCLATURE

R_a	Centre line average	um
R_t	Peak to valley height	um
L_c	Ratio of the thickness of asperities of the texture at certain depth to the sample length.	
A_c	Actual area of contact	mm^2
δ	Diametral interference	um
d	Nominal diameter of the joint	mm
D	Outside diameter of the joint	mm
L	Engagement length	mm
P	Axial load on the joint	kp
T	Torsional torque on the joint	kp.m
μ_s	Static coefficient of friction	
E	Young's Modulus of the material	kp/mm^2
τ	Shear strength of the material	kp/mm^2

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INTRODUCTION

The different factors that affect the holding load of shrink fitted joints may be summarized as:-

1- The mechanical properties; namely the ultimate tensile strength and Young's Modulus of the material of the components;
2- The geometrical dimensions of the joints;
3- The values of interference in the joints;
4- The plastic deformation of the surface asperities due to ageing of the joint; and
5- The surface texture of the mating surfaces.

The effects of the mechanical properties of the material, geometrical dimensions and the values of interferences are fully demonestrated in Lame's equation for cylinders subjected to uniform internal or external pressure and in the work of Conway (1) who showed that the interference required to give a specified radial pressure is inversily proportional to the Young's modulus of the material. The same results were given by Willson (2) who concluded that improvement in the holding load of the joint was obtained when using materials with higher yielding point and higher ultimate tensile strength.

Trock (3) who carried out experiments verifying Lame's equation showed that the radial pressure is a function of the factor $\frac{D^2-d^2}{2d\ D^2}$, i-e. the geometrical dimension of the joint, and that the pressure could be plotted against it as a straight line on the log-log paper. Effect of ageing was also examined by the same author. His results suggest that ageing reduces the holding load almost drastically. However, regarding the surface texture it is perhaps the single most important variable that determines the magnitude of the frictional force between surfaces as it has a great influence in determining the nature and extent of the contact between solids. Its significance on friction is fully appreciated by several researches such as Bowden and Tabor (4), Moore (5) and others (6, 7).

In this field of shrink fitted joints, recent works by Tsuskizoe (8) presented results demonstrating the effects of surface texture on the holding load of the joints. However, no quantitative relations were introduced.

Similar work was conducted by El-Khatib (9) but again analysing such effect theoretically was not fully established.

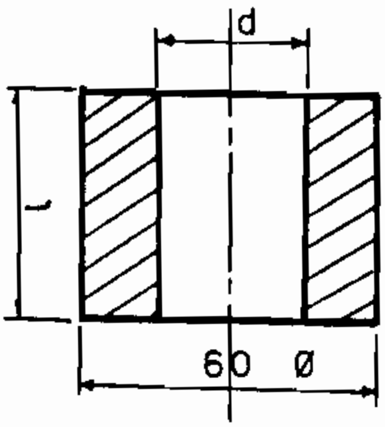
It is then the aim of this work is to establish experimentally the relation between the surface roughness and the holding load both in tension and torsion for statically loaded shrink fitted joints and to suggest the possible parameters that form a base of a model to solve such problem theoretically.

EXPERIMENTAL PROCEDURE

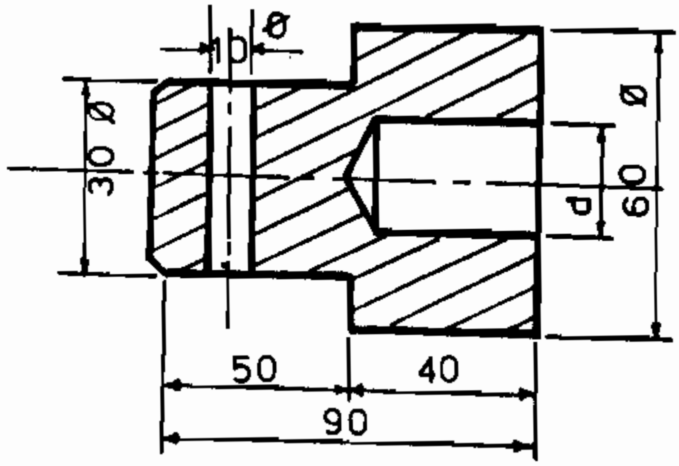
Pairs, Fig. (1), each consists of a shaft and hub made of steel 37 of almost the same surface finish were grouped to form joints of different nominal diameters of 20, 25 and 30 mm with different interferences ranges from 10 to about 140 um. The specimen dimensions were choosen such that the area are the same for the three sets.

The geometrical errors, namely the out of roundness, out of straightness and taperness along the length of engagement were checked and determined. The effect of such errors on the theoretical interferences were considered to determine the actual value of interference for each joint. The roughness of each part was measured and a record of each profile was obtained on a porfilograph model 5.815 FORSTER while the exploring pick up traverses over the specimen. The cut off length used was 2.5 mm with a sampling length of 4 mm. As "R_a" is the parameter believed to have direct relation with the values of interference, it will be the system used here.

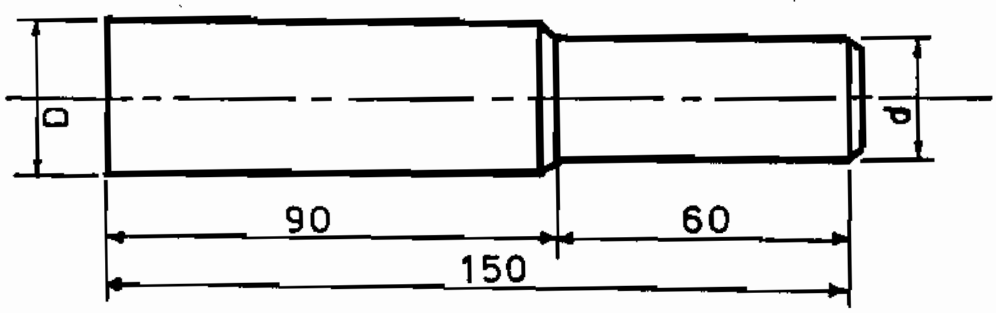
Each pair was, then shrink fitted after heating the hub to 600 ± 10°C. This temperature is below the critical temperature of the material used but is high enough to ensure expansion of the hub by an amount greater than the sum of the values of the interferences and peak to valley of the assperities used in this



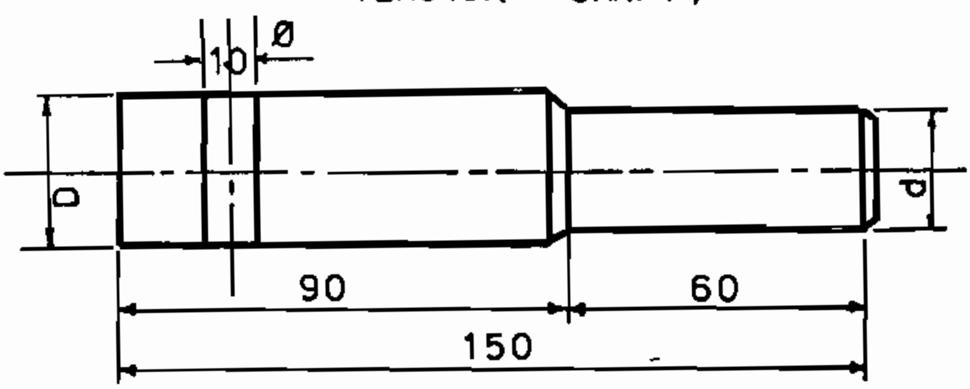
TENSION HUB.



TORSION HUB.



TENSION SHAFT.



TORSION SHAFT.

Length l in mm	40	32	30
Diam. d in mm	20	25	30
Diam. D in mm	27	30	32

FIG (1)

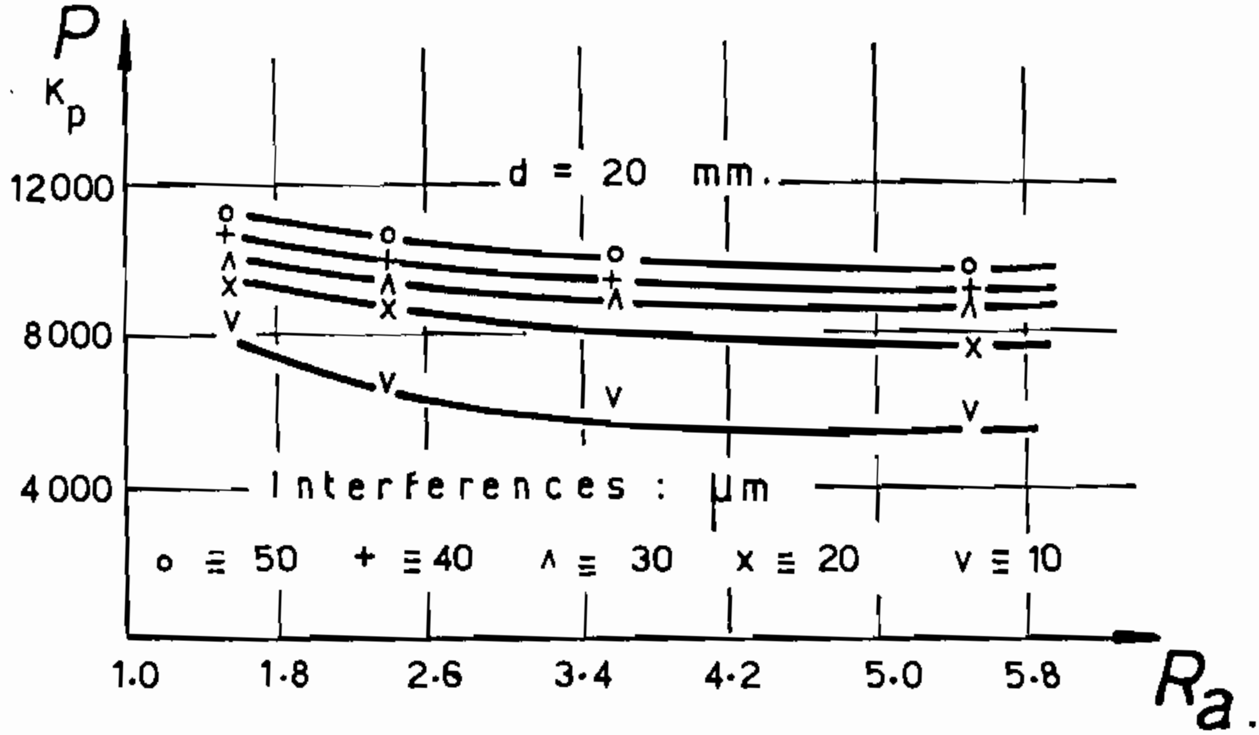

P
Kp
12000
8000
4000
d = 20 mm.
Interferences : µm
o ≡ 50 + ≡ 40 ∧ ≡ 30 x ≡ 20 v ≡ 10
1.0
1.8
2.6
3.4
4.2
5.0
5.8
Ra.

Fig 2-a

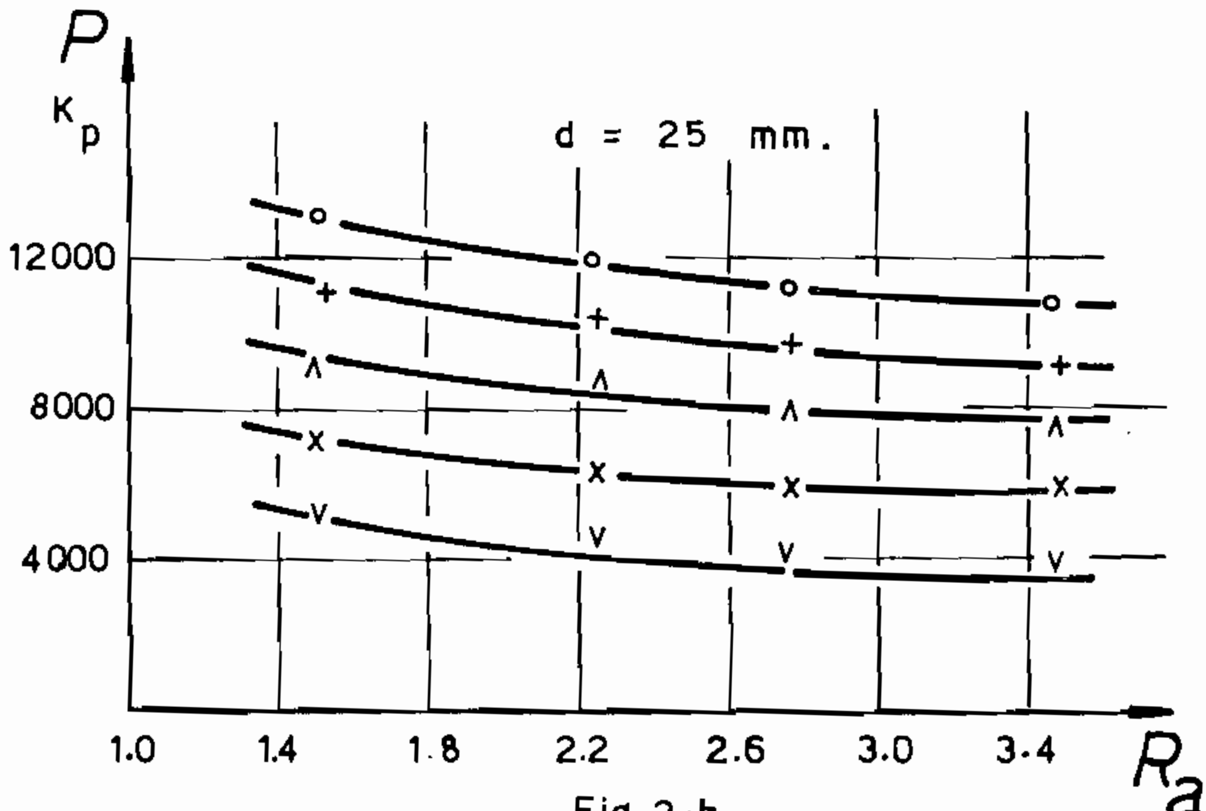

P
Kp
d = 25 mm.
12000
8000
4000
1.0
1.4
1.8
2.2
2.6
3.0
3.4
Ra

Fig 2-b

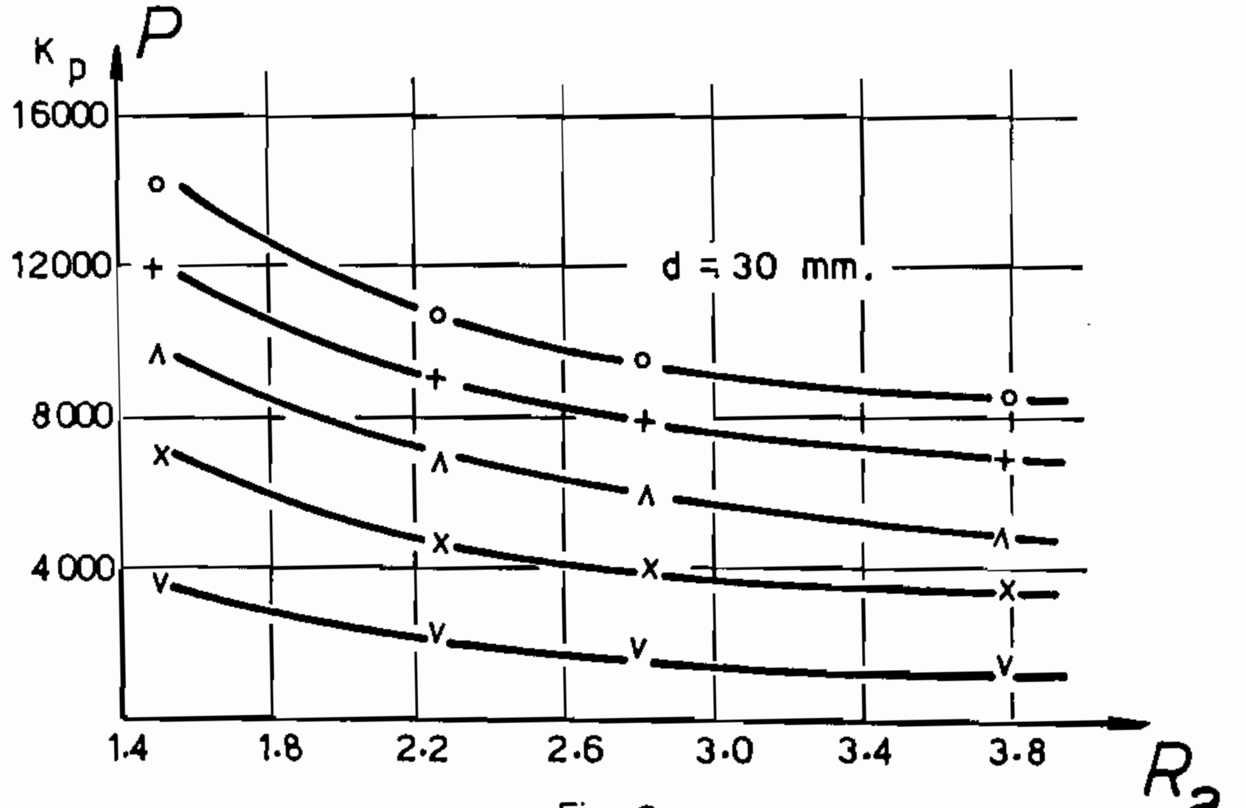


Fig 2-c.

FIG (2)

Variation of holding load in tension with centre line average.

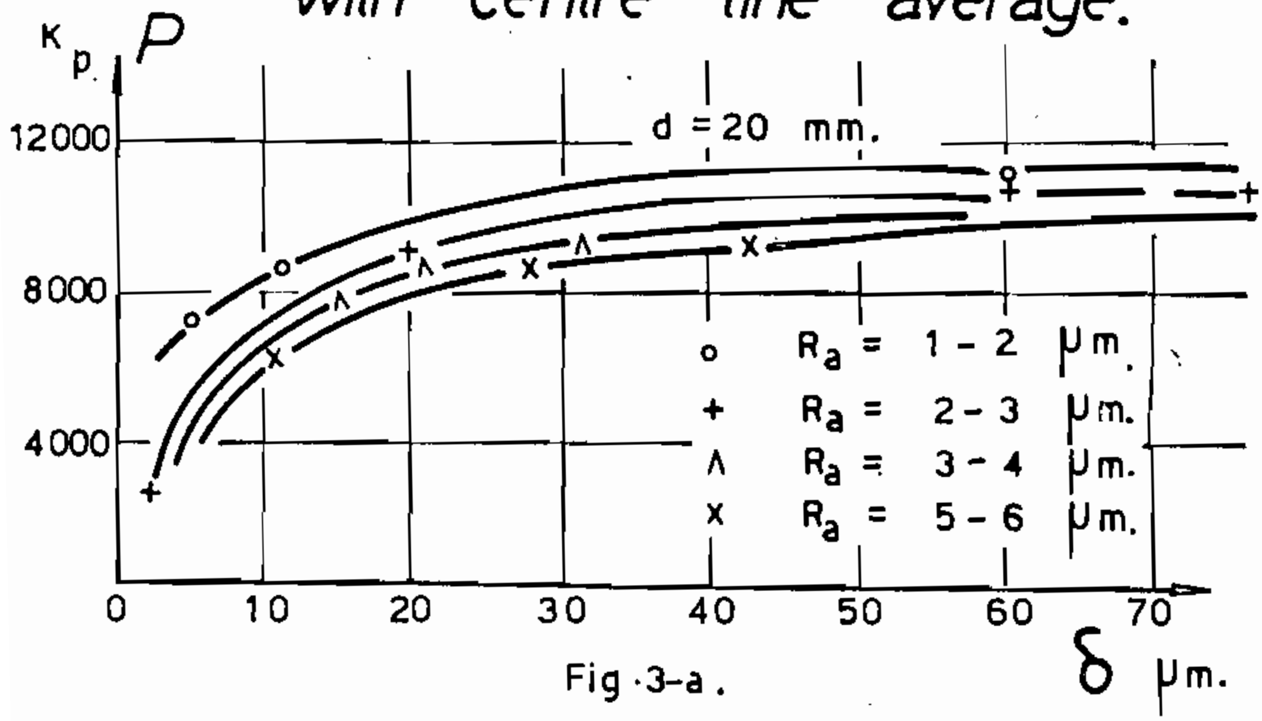


Fig 3-a.

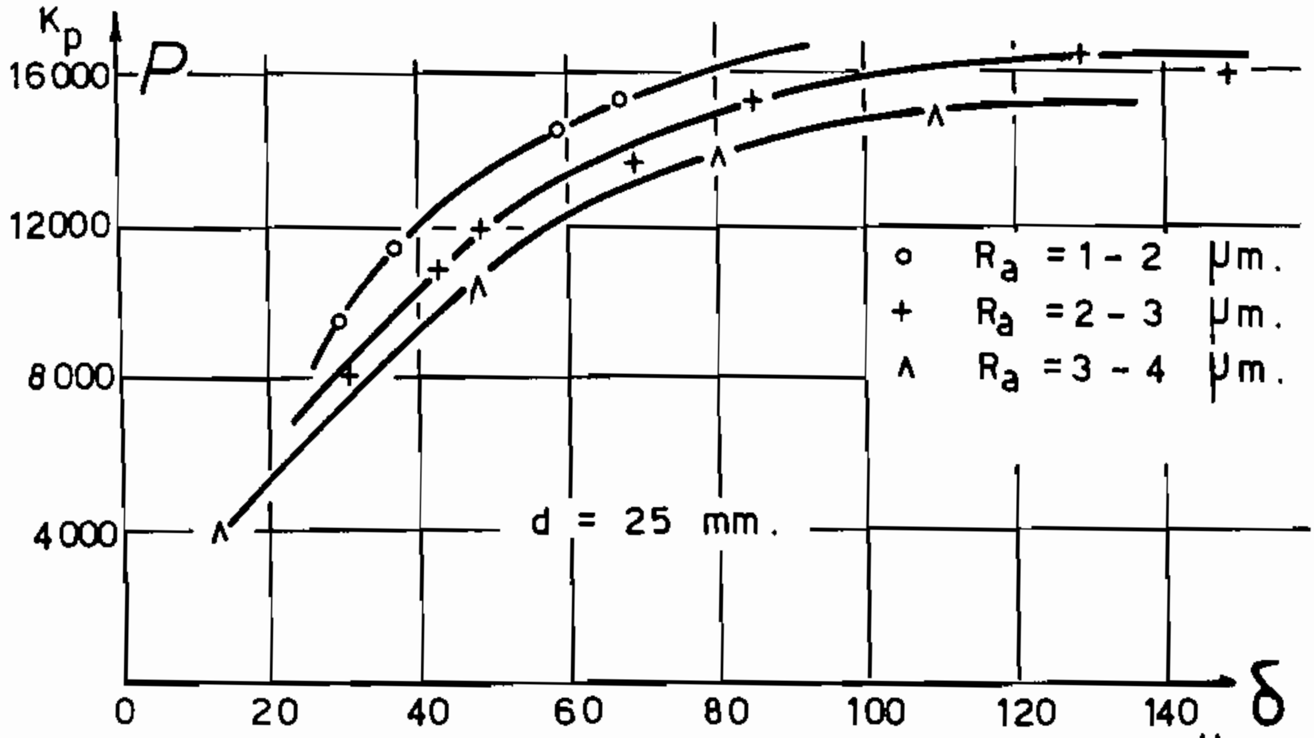


Fig 3 - b

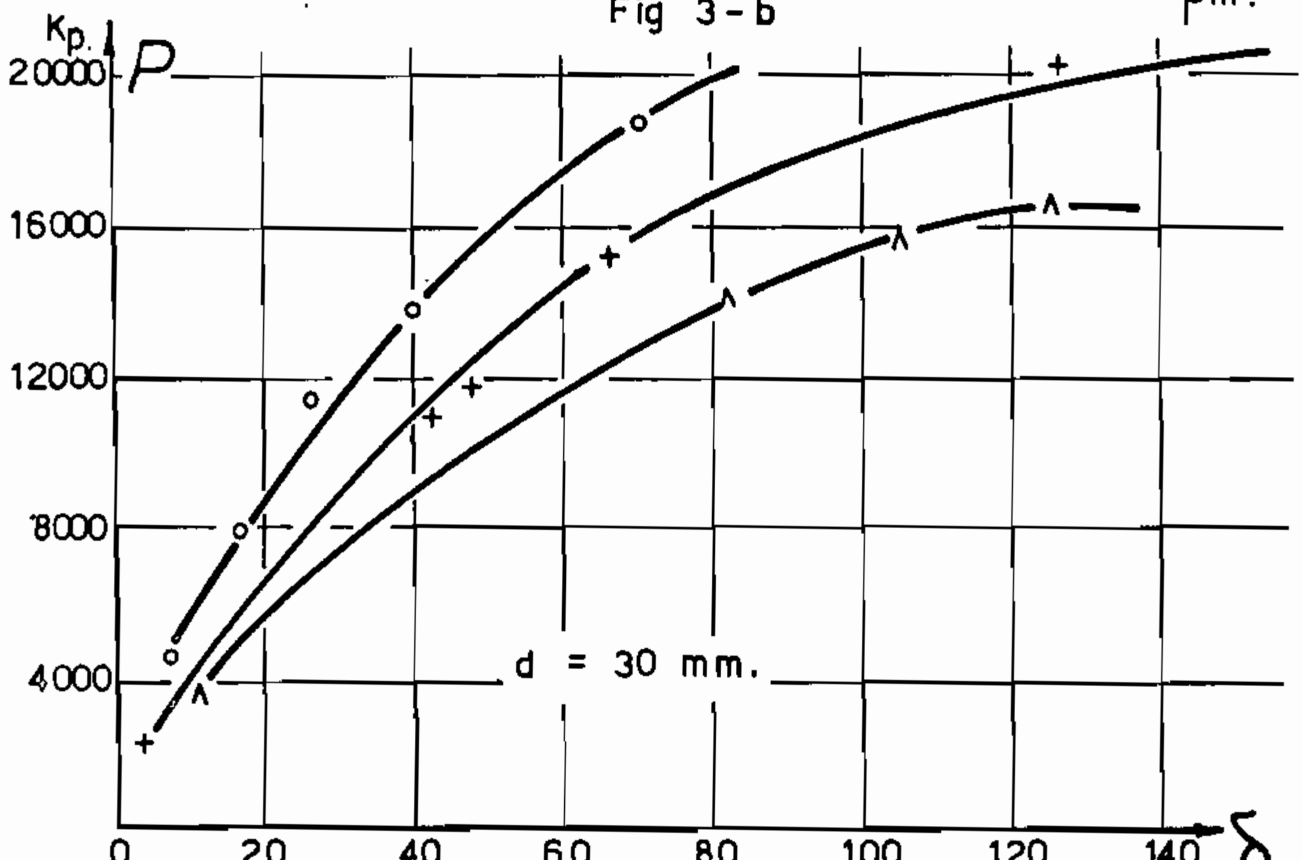


Fig 3 - c

FIG (3).

Variation of holding load in tension with interference.

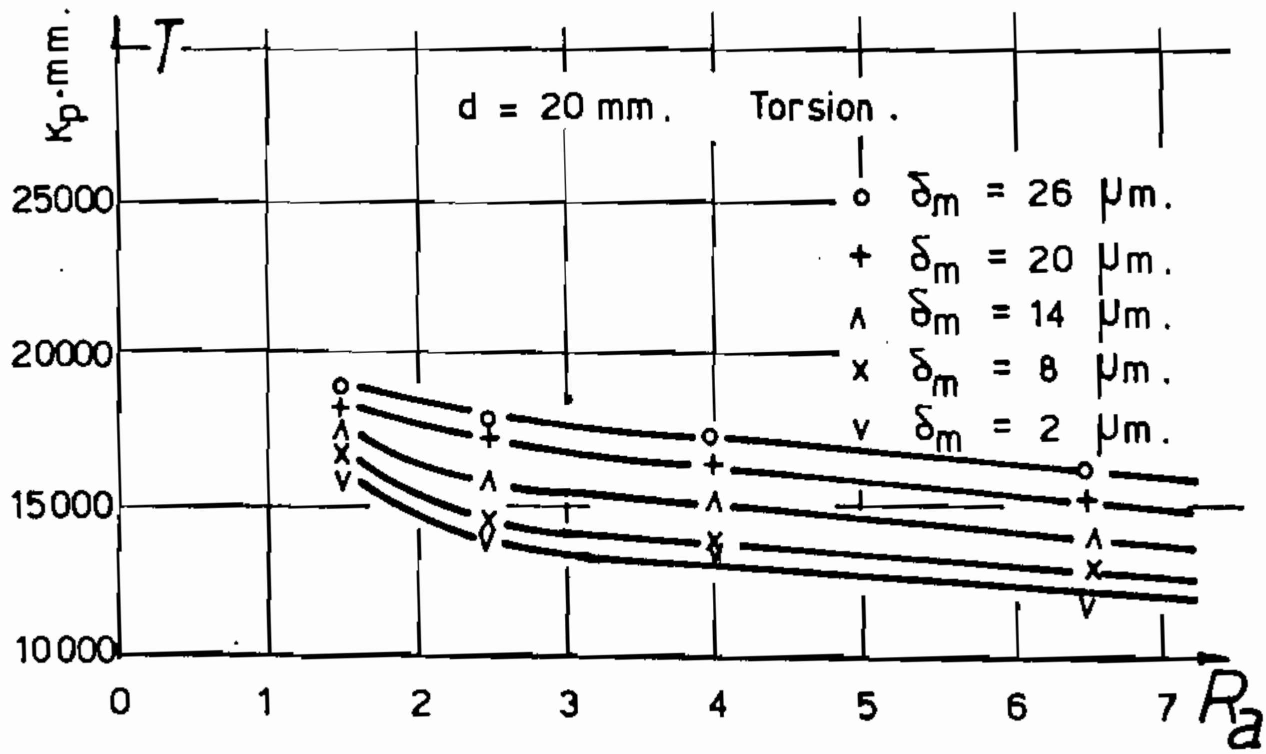

T
$k_p \cdot mm.$
d = 20 mm.
Torsion .
o δ_m = 26 μm.
+ δ_m = 20 μm.
∧ δ_m = 14 μm.
x δ_m = 8 μm.
v δ_m = 2 μm.
25000
20000
15000
10000
0
1
2
3
4
5
6
7
R_a

Fig 4-a .

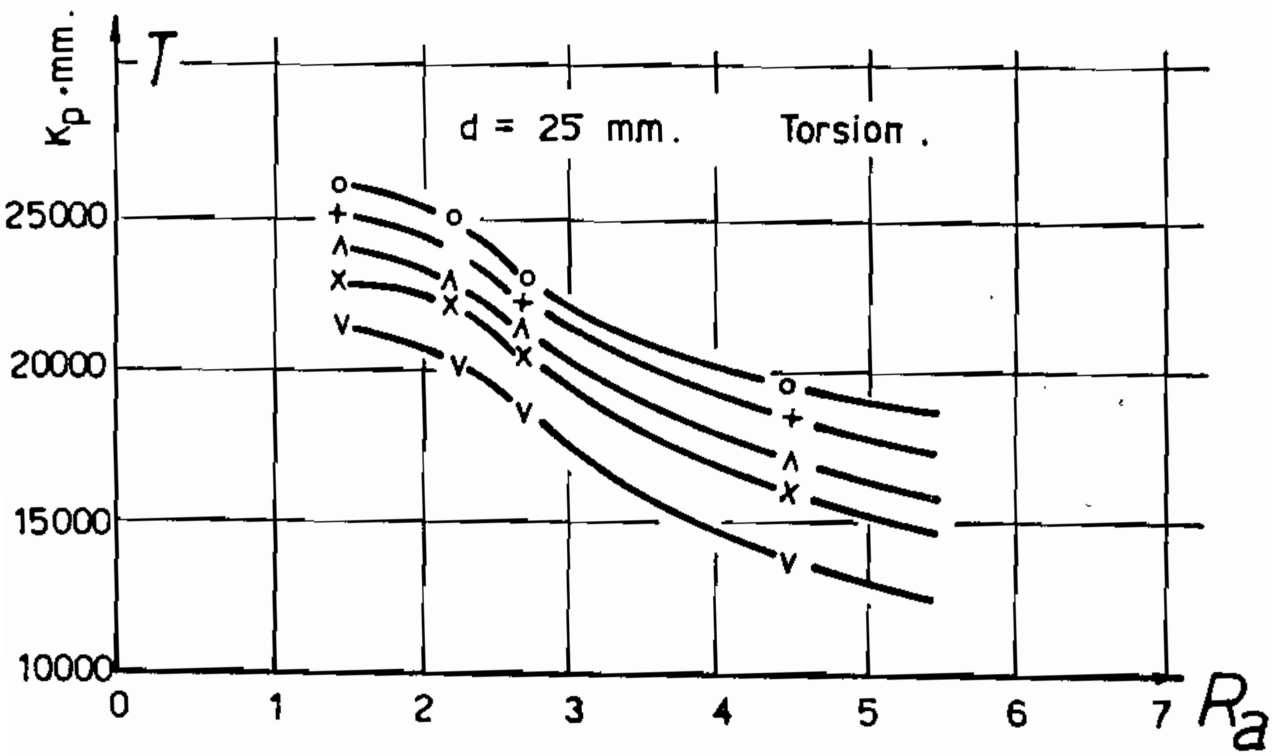

T
$k_p \cdot mm.$
d = 25 mm.
Torsion .
25000
20000
15000
10000
0
1
2
3
4
5
6
7
R_a

Fig 4-b .

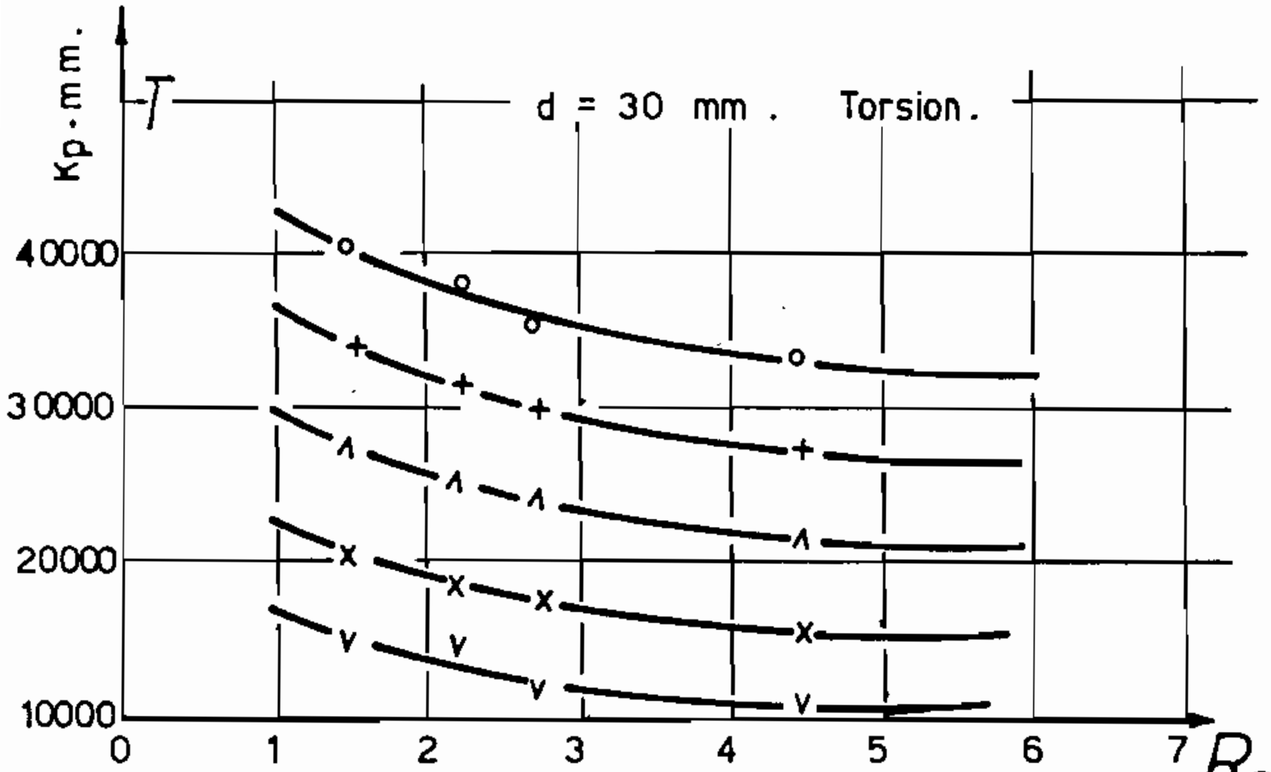


Fig 4-c

FIG (4).

Variation of holding torque with centre line average.

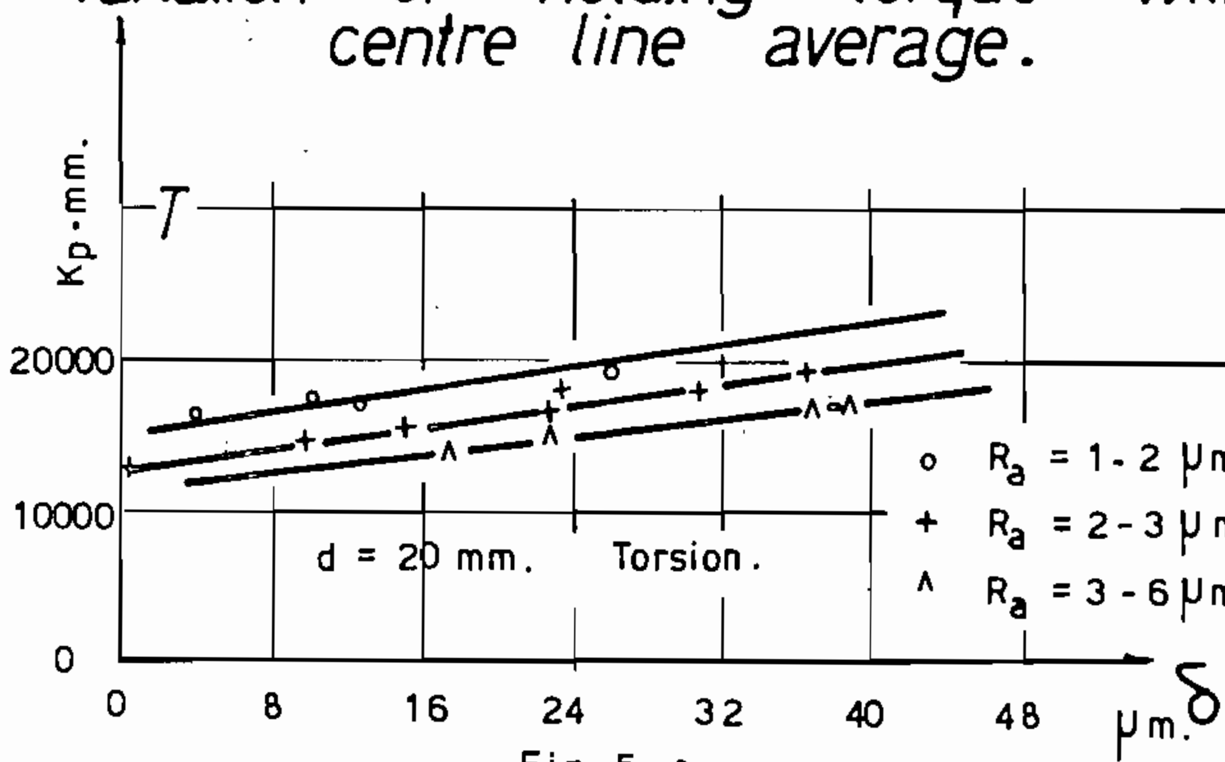


Fig 5-a

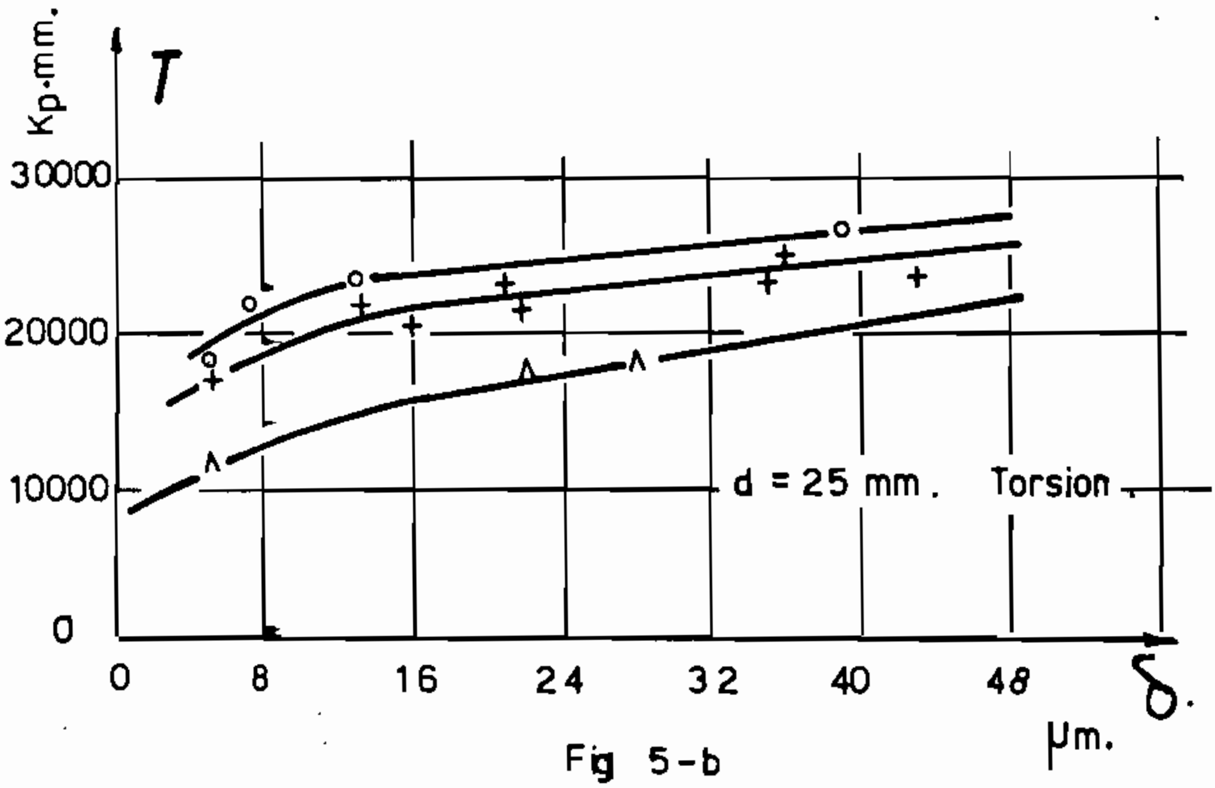


Fig 5-b

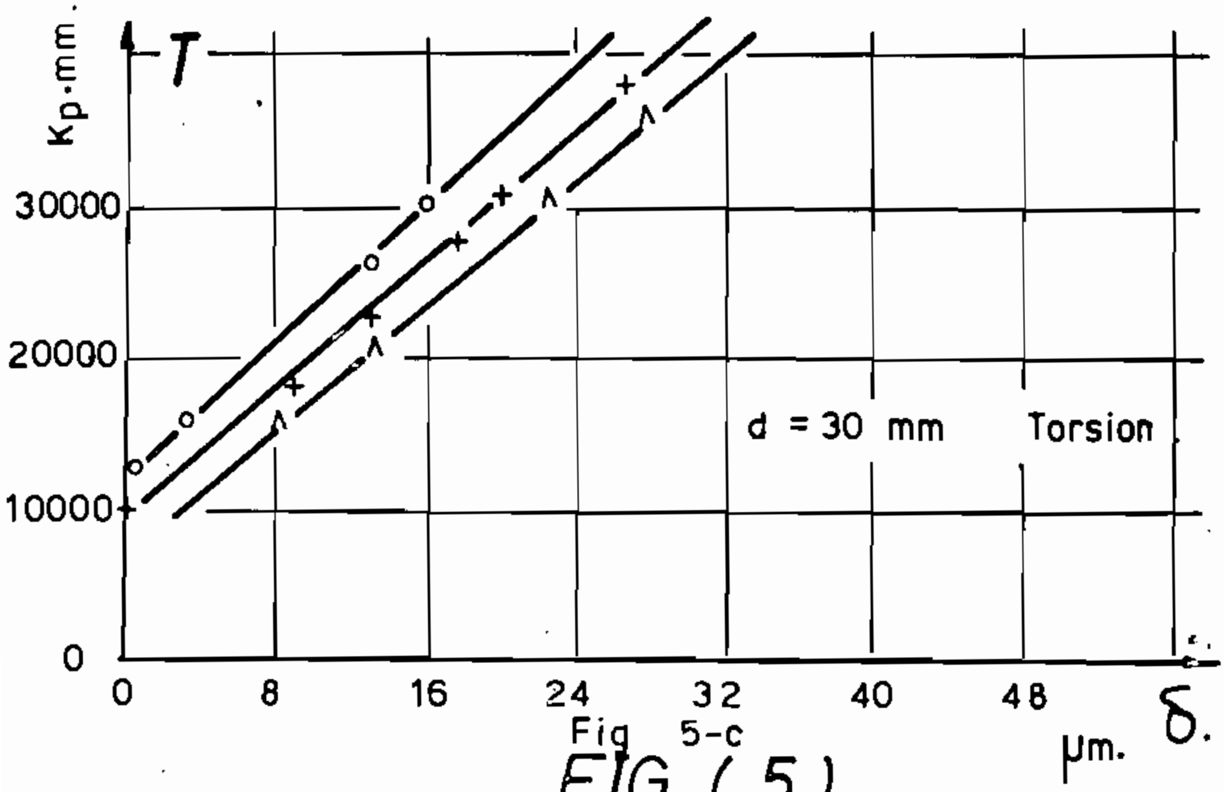


Fig 5-c

FIG (5).

Variation of torsional torque with interference.

investigation. Alighnment between the two parts of the joints was secured during the assembly through the use of a special fixture. This was carried out to minimize any deterioration that may exist to the assperities during fitting.

Tension tests were carried out on a 30 T universal tension machine; hydraulically operated. The load was applied steadilly and was recorded to an accuracy of 0.01 T. Similarly, torsion tests were carried out on a 200 kp.m. universal torsion machine with an accuracy of ± 1%.

RESULTS AND DISCUSSION

The different results obtained for the change in the holding load due to the variation of the surface roughness are given in Fig. 2 for the different sizes. Also, the change in the holding load due to the variation of the mean interference for the different sizes are shown in Fig. 3.

From the curves it can be seen that the strength of the joint increases as the mean value of interference δ increases and as the surface roughness R_a decreases keeping other parameters constant.

For 20 mm joints the increase in the holding load was of high rate as tho interference increases to a value of about 20 - 30 µm; then with much slower rate beyond this value. Such limit increases as the size of the joint increases. e.g. for 25 mm joints this value is between 80 - 90 µm and between 100 - 110 µm for 30 mm joints.

Similarly, the results obtained for the change in the torsional torque with the centre line average, and the mean interference, are shown in Figs. 4 and 5, respectively. The torsional torque, in both, increases as the mean interference increases and decreases as the centre line average of the surface roughness increases.

In fitting a theoretical model to determine the holding load, the stresses developed in the shrink fitted joints are assumed to be due to either the shearing of asperities of the peaks of the surfaces or due to the radial pressure developed between the mating surfaces.

In general, shearing of asperities is assumed to take place, only when the value of interference is less than twice the values of the peak to valley heights of the asperities of the mating surfaces as illustrated in Fig. 6. On the other hand as the interference gets greater than twice the values of the peak to valley the holding load due to the radial pressure will be only considered.

Stresses due to shearing of asperities

To determine the stress due to the shearing of asperities, the actual area of contact between the mating parts is first found. This can be determined by several methods (10, 11); however the one used here is through obtaining the ratio of contact from the bearing area curves. The holding load is then, given by:-

$$P = A_c \cdot \tau$$
$$= \pi \cdot d \cdot L \cdot l_c \cdot \tau$$

Stresses due to radial pressure

The radial pressure "$\bar{P}$" developed between a solid smooth shaft and a smooth hub may be given by (12).

$$\bar{P} = \frac{E}{2} \cdot \frac{\delta}{d} \left(1 - \frac{d^2}{D^2}\right)$$

The holding load is then given by:-

$$P = \pi d \cdot L \cdot \mu_s \cdot \bar{P}$$

Where μ_s is the static coefficient of friction, and it is a function of the surface roughness. The relation used here which relates the two parameters is obtained from the work given by

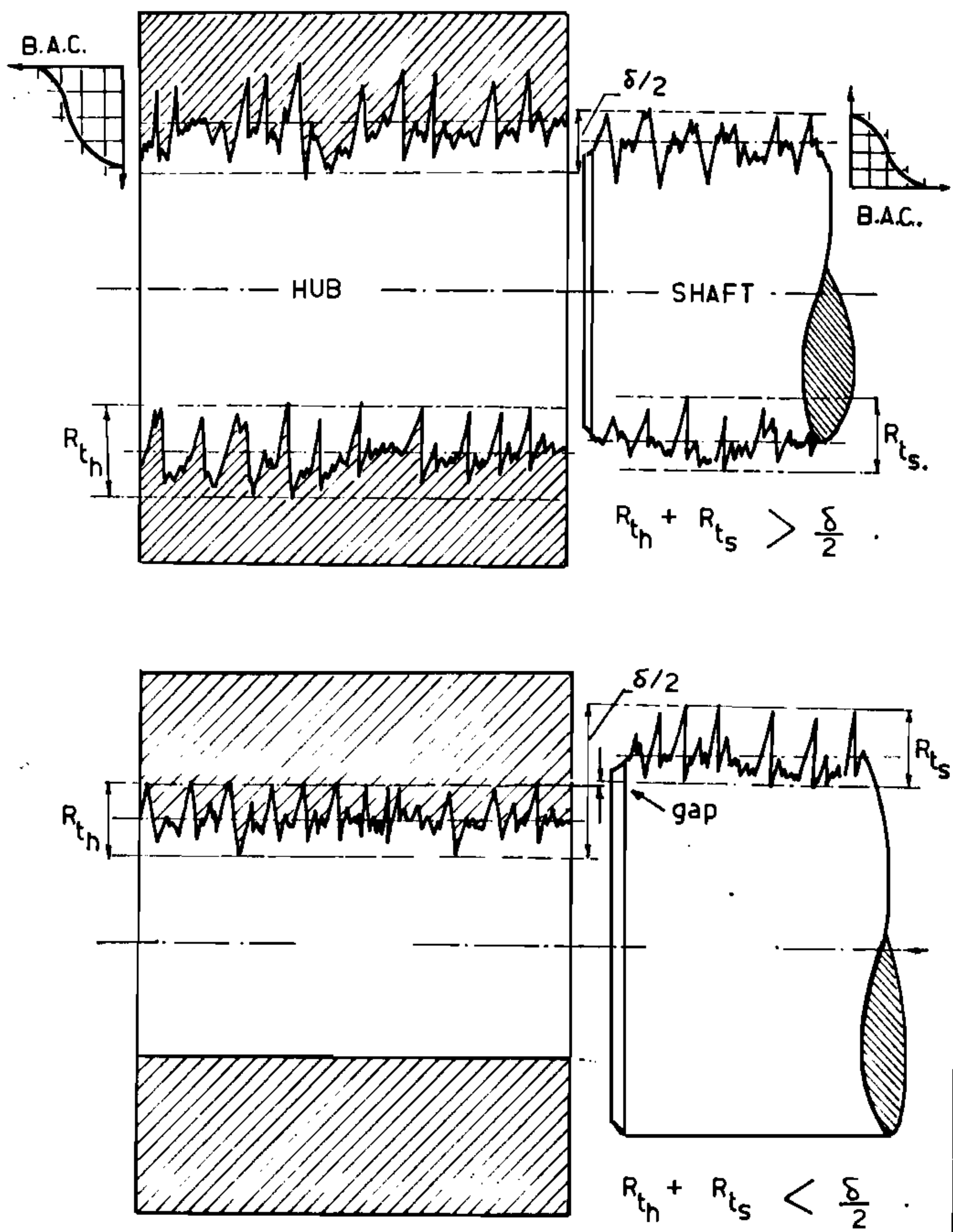

B.A.C.
δ/2
B.A.C.
HUB
SHAFT
R_{t_h}
R_{t_s}
$R_{t_h} + R_{t_s} > \frac{\delta}{2}$.
δ/2
R_{t_s}
R_{t_h}
gap
$R_{t_h} + R_{t_s} < \frac{\delta}{2}$.

FIG (6).

Ghobrial and Zaghlool (13) in which they presented results for steel surfaces having different machining operations. Although the properties of the used steel in the present investigation may be slightly different from that used by Ghobrial but the later claimed that recent work on contact between dry surfaces shows that it is influenced mainly by the nature of the uppermost part of the surfaces. In general the relation used taking the mutual approach as 0.0107 is:

$$\mu s = 0.1286 + 10^{-4} \left[18\ \theta + 60\ \text{Log}\ (\sigma_p .\ G/R_a) \right]$$

where: μ_s is the initial asperity angle and is given by:

$$\tan\theta = R_t / \ (3.12\ R_t + 15.1)$$

σ_p is the standard deviation of the peak distribution
G is the depth smoothness

Figs. 7 and 8 show the theoretical computed values for the axial holding load of the joints for two values of interferences, 10 and 50 μm; while Fig. 9 gives those for torsion for 8 μm interference only in order to avoid confusion.

Each set contains two curves obtained from the above theoretical equations and also the corresponding experimental one; the conditons are the same within each set.

The position and the trend of the experimental curves for the holding load were found to follow that of the theoretical curves deduced from the shearing action of the asperities of the mating surfaces. This suggest that the power of the shrinkage fitted joint is mainly due to the shearing action of the interlocked asperities. This is valid till $\frac{\delta}{2} < R_{t_h} + R_{t_s}$. However as $\frac{\delta}{2}$ gets greater than this conditon, the conclusion is not valid any more and the load may be, then, estimated from the friction equation. For torsional torque curves, this was also found true but for small values of interferences only.
In general the difference between the experimental results and the corresponding theoretical results obtained from the shear equation in the case of torsion is atributed to the error in

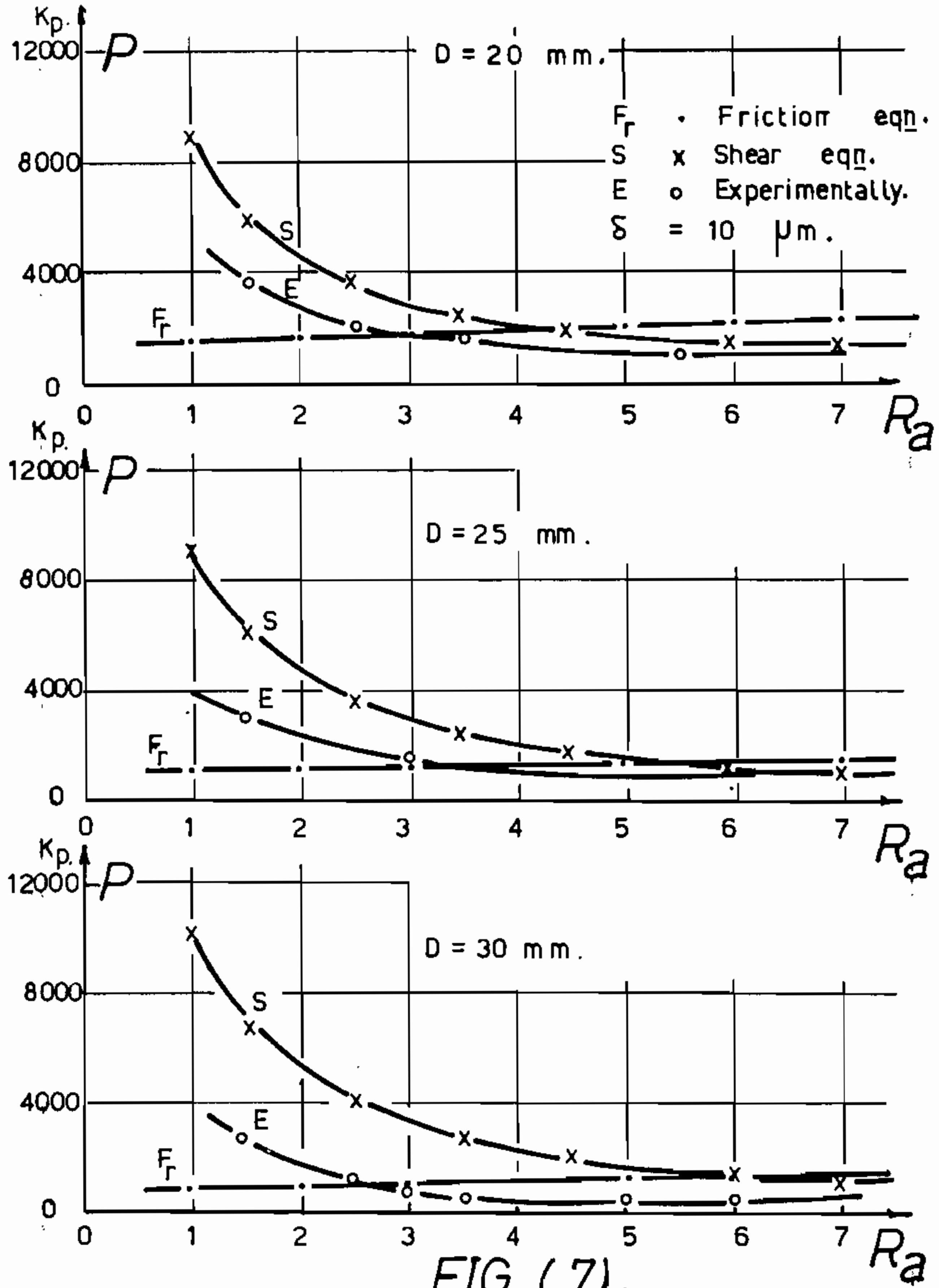

Kp.
P
D = 20 mm.
Fr • Friction eqn.
S x Shear eqn.
E o Experimentally.
δ = 10 μm.
12000
8000
4000
0
S
E
Fr
0 1 2 3 4 5 6 7
Ra
D = 25 mm.
D = 30 mm.

FIG (7).

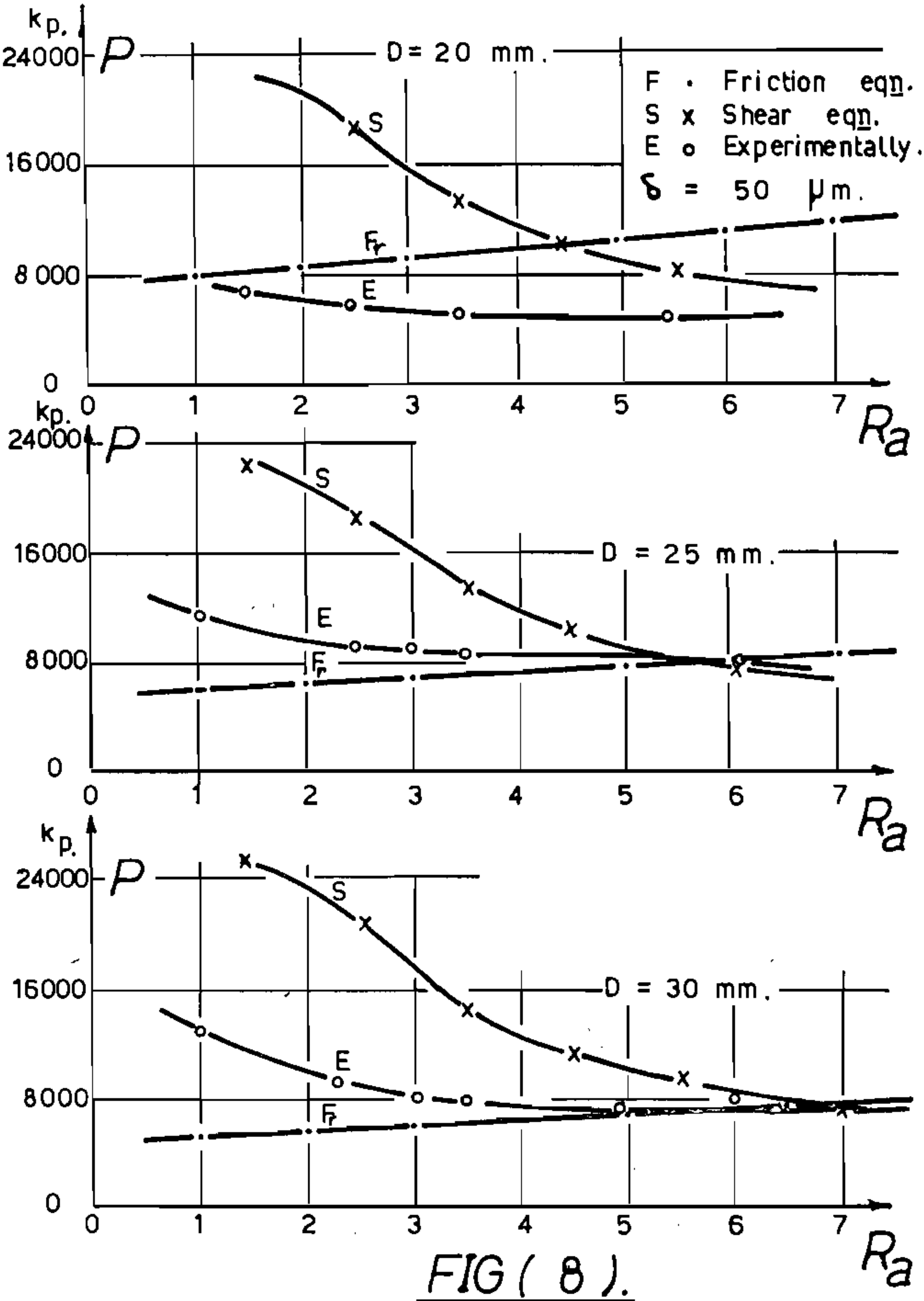

kp.
P
D= 20 mm.
F · Friction eqn.
S x Shear eqn.
E o Experimentally.
δ = 50 μm.
S
Fr
E
Ra
D = 25 mm.
D = 30 mm.
0
8000
16000
24000
0 1 2 3 4 5 6 7

FIG (8).

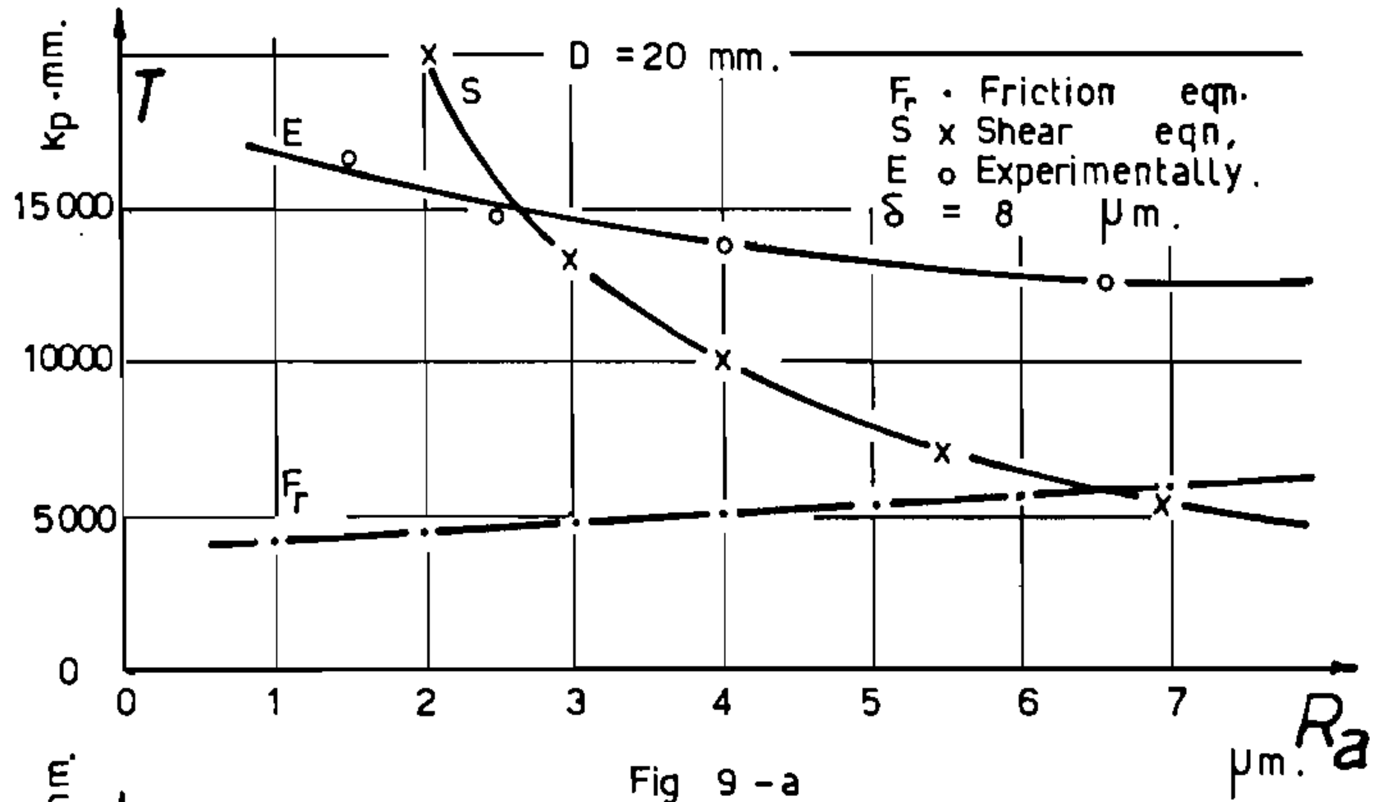

T
kp·mm.
D = 20 mm.
Fr · Friction eqn.
S x Shear eqn,
E o Experimentally.
δ = 8 μm.
E
S
Fr
15000
10000
5000
0
0
1
2
3
4
5
6
7
Ra
μm.

Fig 9 - a

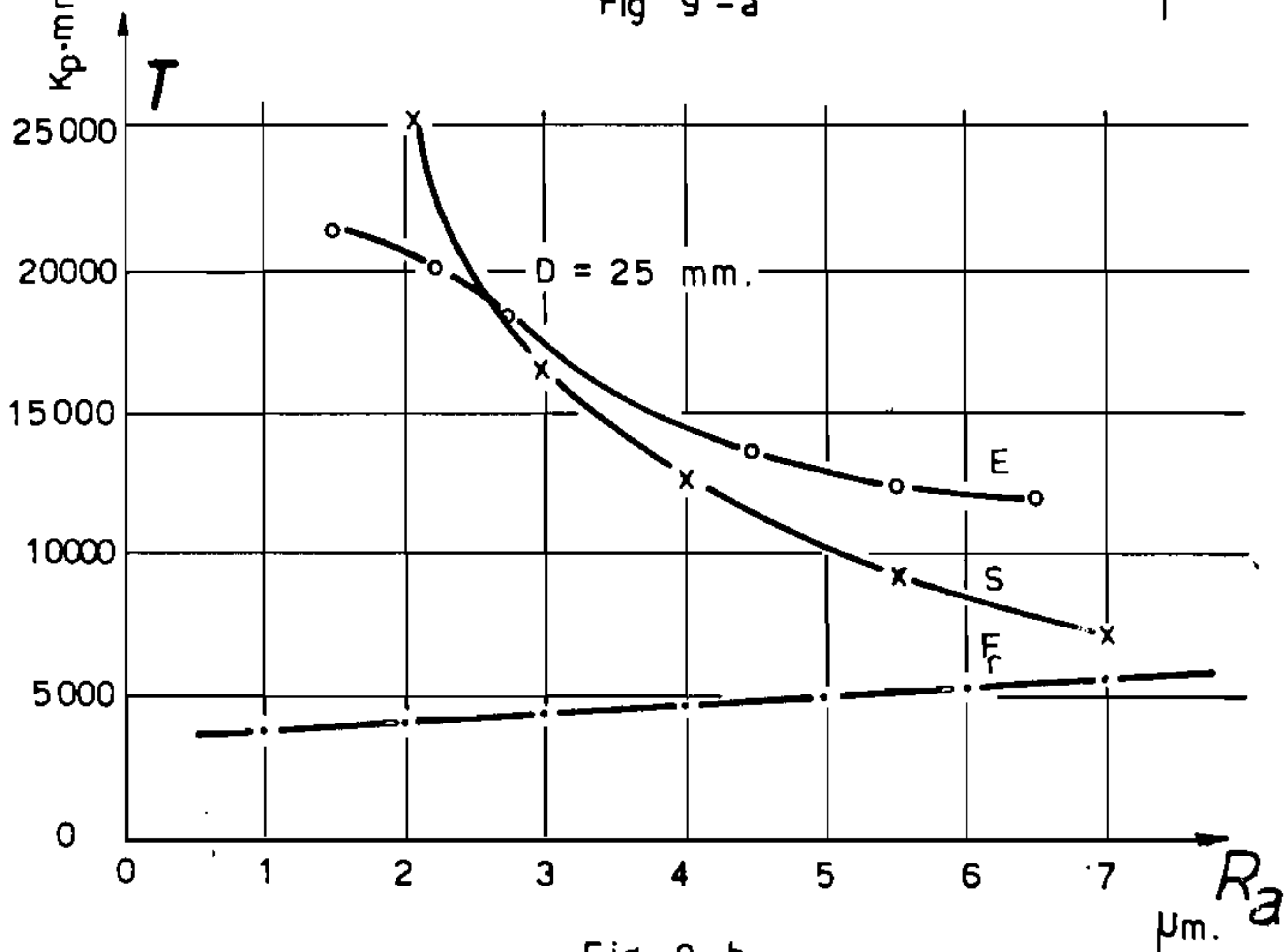

T
kp·mm.
D = 25 mm.
E
S
Fr
25000
20000
15000
10000
5000
0
0
1
2
3
4
5
6
7
Ra
μm.

Fig 9 - b

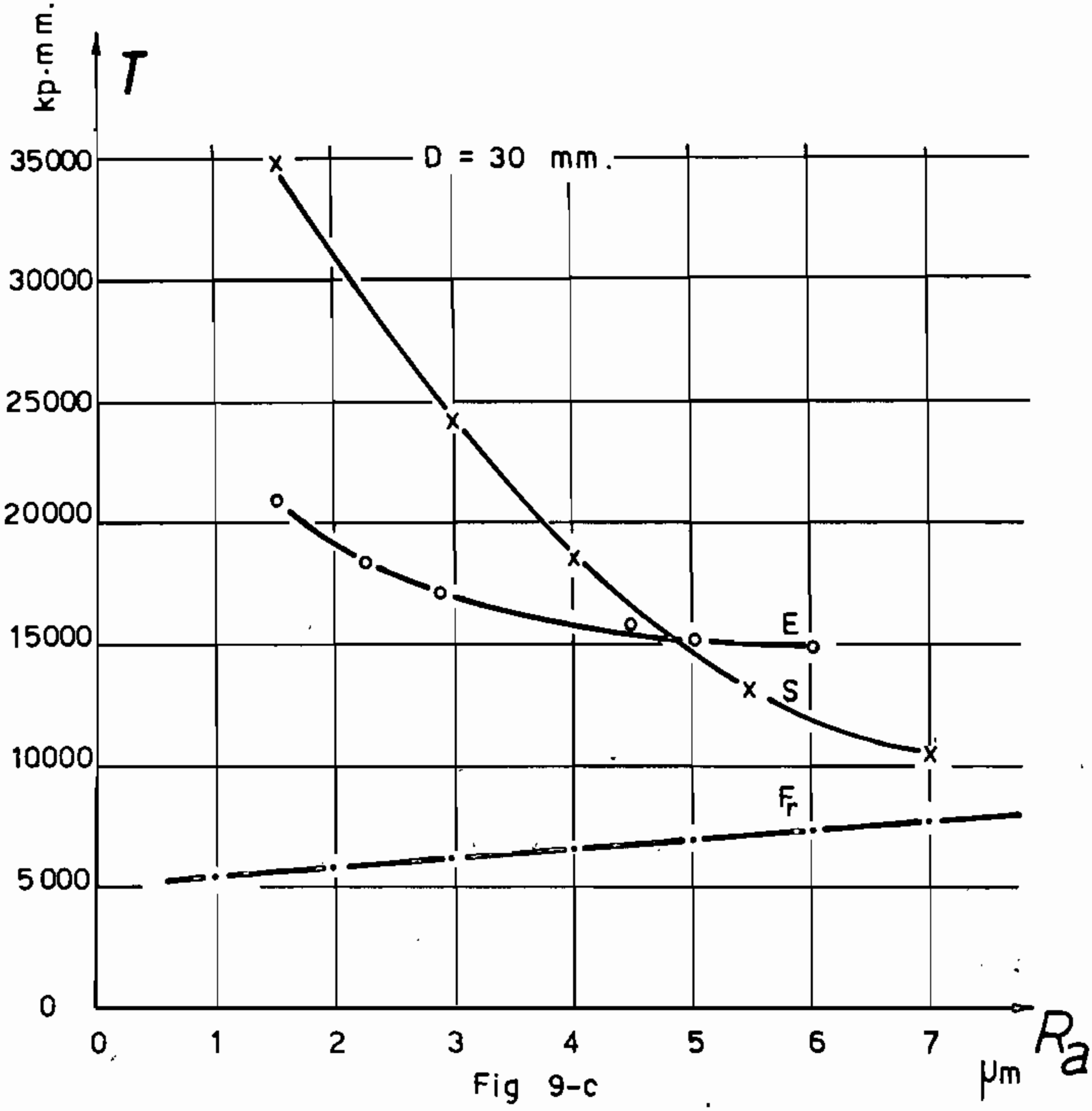

T
kp·mm.
D = 30 mm.
35000
30000
25000
20000
15000
10000
5000
0
E
S
F_r
0
1
2
3
4
5
6
7
R_a
μm

Fig 9-c

FIG (9).

estimating the actual area of contact from the bearing area curves, as this was computed from traces taken on relatively smooth surfaces while the stylus travels along the lay on a curved surfaces. This difference diminishes as the surfaces get rougher.

CONCLUSION

From all the foregoing it may be concluded that the strength of the shrink - fitted joints either in tension or torsion is mainly affected by the degree of surface roughness. It increases as the value of R_a decreases. For small interferences i.e. $\frac{\delta}{2} < R_{t_s} + R_{t_h}$, the theoretical model that appear to fit is that due to the shearing of asperities. However it is recommended to verify it further using a model such as the finite element technique taking its element the parameters considered here.

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