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A comparative study of the performance of Tufftrided and Sursulf-treated low-carbon steel gears*

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Abstract

Low-carbon steel gears subjected to different surface treatments, Tufftride TF1 and Sursulf were tested in a back-to-back gear test rig. The type of failure has been studied and the effect of contact stress on life has been investigated. The studies indicate that both the treatments lead to satisfactory performance of gears, Sursulf yielding slightly better results.

Key words: Surface durability, Tufftride and Sursulf treatments, gears.

1. Introduction

Gears used in industrial applications such as textile looms, machine tools where the loads are small require a hard wear resistant case, the core strength being not critical. The usual methods of case hardening gears are carburizing, nitriding, flame hardening and induction hardening. Cyaniding, used occasionally, is a highly toxic process and the disposal of waste salts poses a problem because of environmental regulations. Research work in Europe has resulted in low temperature non-polluting salt-bath treatments which are superior to traditional cyaniding in many respects. The air accelerated salt-bath treatment developed in W. Germany is known as Tufftriding[1]. Sursulf[2] is the sulphur-accelerated salt-bath treatment perfected in France.

Tufftriding, sometimes called soft nitriding, is useful in the treatment of all ferrous materials; treatment is performed for an average period of 100 minutes. In the presence of ferrous materials, the Tufftride bath liberates carbon and nitrogen. Nitrogen and a little carbon diffuse into the surface of immersed parts to form an outer compound zone. This compound zone essentially consists of epsilon iron nitride, which is ductile, and some iron carbide[3]. The compound zone is about 10 microns in thickness. Nitrogen, which diffuses beyond the compound zone, forms a diffusion zone where it is held in solid solution. The diffusion zone is about 800 microns thick. Tufftride process has been found to have several advantages. The treatment time is short and the treated parts exhibit low thermal distortion, considerable improvement in bending fatigue strength, wear, scuffing and anticorrosive properties[1].

Sursulf treatment is similar to Tufftride treatment, but with the addition of sulphur. The compound zone is slightly deeper, about 18 to 20 microns, and is porous at and near to the surface. The porous zone contains sulphur which confers on the parts improved

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resistance to scuffing and seizure[4]. Another advantage is that it is less toxic compared to Tufftriding.

For lightly-loaded gears, low-strength steels are best suited due to their easy availability and low cost. In the untreated condition these steels fail by plastic deformation even under very low loads and hence are unsuitable[5]. The surface durability characteristics of these steels can be improved by any one of the salt-bath treatments referred above. The present work compares the performance characteristics of Tufftride and Sursulf-treated gears.

2. Experimental details

Specifications of the gears tested are given in Table I. The material used for the gears was a plain carbon steel containing 0·24 per cent carbon. The mechanical properties of this steel are shown in Table II. The gear blanks were cut from rolled plate and machined on a lathe to standard tolerance limits. The gears were then hobbed on a gear-hobbing

Table I
Specifications of the gears tested

Details		Gears used in experiments	
		1 and 2	3 to 6
Number of teeth	z	$z_1 = 20$ $z_2 = 55$	$z_1 = 37$ $z_2 = 38$
Gear ratio	u	2·75	1·03
Module	m (mm)	5	5
Face width	b (mm)	50	35
Pressure angle	α_0(deg)	20	20
Centre distance	a_0(mm)	187·5	187·5
Pitch diameter	d_0(mm)	$d_{01} = 100$ $d_{02} = 275$	$d_{01} = 185$ $d_{02} = 190$

Suffix 1 for pinion and 2 for gear .

Table II
Mechanical properties of steel used for gears

Ultimate tensile strength	MPa	500
Yield strength	MPa	300
Percentage elongation at failure	(–)	21
Hardness after treatment (both Sursulf and Tufftride)	VPH	720
Untreated hardness	VPH	185
Modulus of elasticity	MPa	2×10^5

machine and chamfered at the edges to minimize stress concentration effects. Gears used in experiments 1 to 4 were subjected to Tufftride TF1[®] treatment and 5 and 6 to Sursulf treatment for a duration of 100 minutes.

The tests were conducted using a back-to-back power recirculation gear test rig of the type represented in fig. 1. The rig consisted of two identical gear housings, each one accommodating a gear pair. The two housings were connected by input and output shafts. The power required to drive the test rig was only that required to overcome losses due to tooth friction, bearing friction, windage and oil drag. Loading was accomplished by a lever using dead weights (not shown). This method of loading required a special torsion coupling which was incorporated in the shaft connection between the gears. The gears were lubricated with Tellus 33 oil (viscosity 0·0577 Pa.s at 38°C) by drop feeding under gravity. Power for running the gears was provided by a 3·4 kW, 960 rev/min, 3-phase electric motor through 1-to-1 double vee belts. The gear test programme is indicated in Table III.

The test programme was executed in two phases. Experiments 1 and 2 (velocity ratio 2·75) comprised the first phase and experiments 2 to 6 (velocity ratio 1·03) were conducted in the second phase. The purely practical consideration of availability of material was the reason for changing the velocity ratio for the second phase of experiments. It was presumed that the change in velocity ratio has no significant effect on the performance of gears.

In gears, the contact stress between a pair of teeth depends upon the radii of curvature at the point of contact and hence changes from beginning to end of engagement. The contact stress at any position on the path of contact may be determined by suitably modifying the Hertzian equation for two cylinders in contact[7]. However, in gear design work, the contact stress at pitch point is the one usually considered as is done in the present work.

The torques applied on the pinions were selected to produce a good variation of contact stress at the pitch point—485 to 745 MPa for Tufftrided gears and 650 to 745 for Sursulf-treated gears. More number of tests are planned for Sursulf-treated gears.

Table III
Gear test programme

Expt No.	Treatment	Torque applied on opinion T_1 N.m.	Velocity ratio, i	Contact stress at pitch point MPa
1.	Tufftride	200	2·75	485
2.	Tufftride	470	2·75	745
3.	Tufftride	420	1·03	550
4.	Tufftride	500	1·03	600
5.	Sursulf	585	1·03	650
6.	Sursulf	770	1·03	745

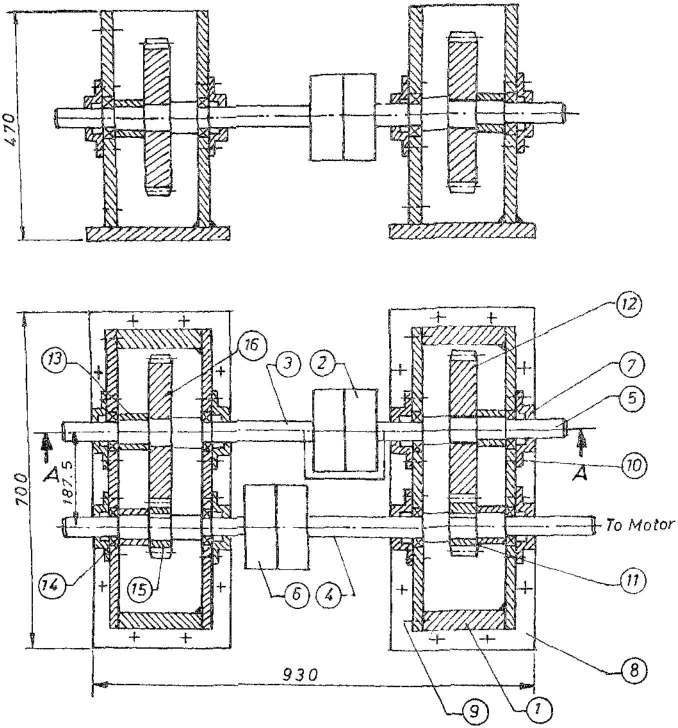

Fig. 1. Gear test rig assembly.

1. Gear housing
2. Drive coupling
3. Test gear shaft
4. Load pinion shaft
5. Load gear shaft
6. Torsion coupling
7. End cover
8. Base plate
9. Bolt M-10
10. Screw M-10
11. Load pinion
12. Load gear
13. Spacer
14. Bearing
15. Test pinion
16. Test gear

3. Results and discussion

In all tests, the surfaces of the gear teeth were inspected at regular intervals using a hand-held magnifying glass and a test lamp. There was no failure in the case of experiments 1 and 3—contact stresses 485 and 550 MPa respectively for Tufftrided gears and experiments 5—contact stress 650 MPa for Sursulf-treated gears. These tests were terminated at about 10^7 cycles. At the end of each test the gears were removed from the rig and thoroughly cleaned for visual examination. Except for polishing of the surfaces of the teeth, no other failure was noticed.

In the case of experiment 4, which is Tufftrided, small pits were observed on two teeth of the load pinion and one tooth of the test pinion at about 10^6 cycles (contact stress 600 MPa). However, the surface area of the pit on the test pinion increased with further running and peeling of the surface layer was noticed as shown in fig. 2. When the test was terminated at about $2{\cdot}6\times10^6$ cycles, peeling was observed on 6 teeth of the test pinion and pits on 15 teeth of the load pinion. To determine the number of cycles for initiation of failure, the following procedure was adopted. The area of the peeled zone of the tooth where failure was first noticed was measured at various stages from impressions in fig. 2. This area, expressed as a percentage of the tooth surface area, was plotted against the number of cycles run. Plots were made both on log–log co-ordinates and semi-log co-ordinates to find the best fit. The semi-log plot turned out to be a good straight line (fig. 3) and from this plot the number of cycles to the initiation of peeling (corresponding to zero per cent peeled area) was found by extrapolation to be 9×10^5 cycles.

The load pinion in this experiment (*i.e.* 4) failed by pitting. In this case, the total number of pits on the pinion were plotted against cycles run. On log–log co-ordinates (also drawn in fig. 3) this plot turned out to be a good straight line. The number of cycles run before formation of the first pit was determined by extrapolation. These figures show that for experiment 4 the number of cycles to the initiation of peeling on the test pinion and to the initiation of pitting on the load pinion are approximately the same (9×10^5 cycles). It has not been possible to give any specific reasons for the development of two different types of failures although material inhomogeneities and lubricant effects are suggested as possible causes.

In experiment 2 on Tufftrided gears (contact stress 745 MPa) both test pinion and load pinion failed by pitting. Figure 4 shows a log–log plot of number of pits on test pinion against cycles run which is a straight line. The number of cycles to formation of the first pit was found to be $1{\cdot}2\times10^5$.

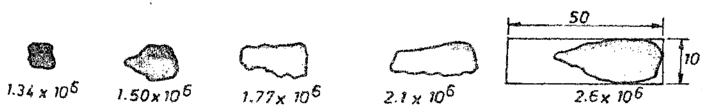

Fig. 2. Peeled area impressions.

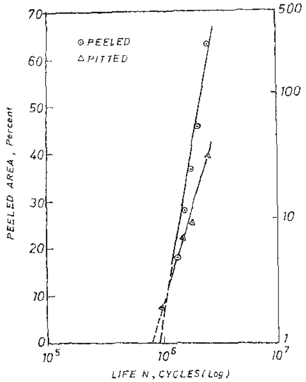

Fig. 3. Determination of pitting life in experiment 4.

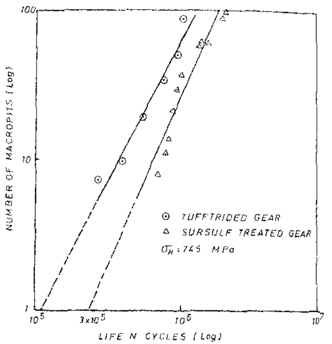

Fig. 4. Relation between number of pits and number of cycles run.

Experiment 6 is on Sursulf-treated gears and the stress level is the same as in experiment 2, *i.e.*, 745 MPa. The failure is by pitting. For the sake of comparison, the total number of pits on the test pinion with cycles run is also shown in fig. 4. The growth rate of the number of pits in both the experiments—one Tufftrided and the other Sursulf-treated—appears to be approximately the same.

However, Sursulf-treated gears yield a pitting life approximately three times that of Tufftrided gears for the same contact stress of 745 MPa.

In the above investigations a total of 12 pinions were tested. In the failed pinions, except for 1, irrespective of the treatment, the failure was due to pitting. Thus, it may be concluded that for liquid nitrided gears, there is a greater probability of pitting than peeling. However, one distinguishing feature between Sursulf-treated and Tufftrided-gears tested was that under identical conditions the size of pits was much larger in Tufftrided-gears than Sursulf-treated gears.

The number of cycles run before one pit formed or peeling was initiated was considered to represent the onset of surface failure. The quantity (N) is shown plotted against the corresponding Hertzian stress levels σ_H on log–log co-ordinates as indicated in fig. 5. As adequate points are available, the S–N diagram for Tufftrided-gears could be plotted as indicated by the full curve. This curve is similar in shape to conventional S–N curve obtained in fatigue experiments. It has two regions, an inclined line representing finite life and a horizontal line representing infinite life. The knee of the curve occurs at

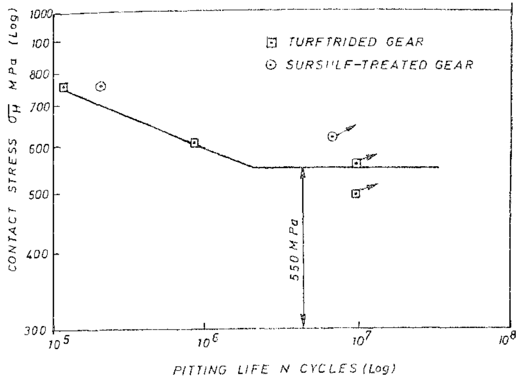

Fig. 5. Variation of pitting life with contact stress.

2×10^6 cycles. From the figure, it can be seen the surface fatigue endurance limit of Tufftrided low-carbon steel gears is 550 MPa.

The points from Sursulf-treated gears fall above the (S–N) curve indicating the better performance of the latter. The presence of sulphur in the compound zone appears to be the cause for the improved performance.

4. Conclusions

Results of experimental investigations on hobbed low-carbon steel gears subjected to two different liquid nitriding treatments—Tufftride and Sursulf-conducted in a back-to-back gear test rig have been presented. These investigations reveal that Tufftrided-gears perform satisfactorily and the surface-fatigue endurance limit has been found to be 550 MPa. The performance of Sursulf-treated gears was superior and appears to be due to the presence of sulphur in the compound zone. As manufacturing and material costs become more and more critical, it is advantageous to use these treatments to improve markedly the surface fatigue characteristics of cheap low-carbon steels.

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