



The effect of surface roughness on the fatigue limit of steels (at zero mean stress)

Endorsed by
The Royal Aeronautical Society
Institution of Mechanical Engineers

ESDU DATA ITEMS

Data Items provide validated information in engineering design and analysis for use by, or under the supervision of, professionally qualified engineers. The data are founded on an evaluation of all the relevant information, both published and unpublished, and are invariably supported by original work of ESDU staff engineers or consultants. The whole process is subject to independent review for which crucial support is provided by industrial companies, government research laboratories, universities and others from around the world through the participation of some of their leading experts on ESDU Technical Committees. This process ensures that the results of much valuable work (theoretical, experimental and operational), which may not be widely available or in a readily usable form, can be communicated concisely and accurately to the engineering community.

We are constantly striving to develop new work and review data already issued. Any comments arising out of your use of our data, or any suggestions for new topics or information that might lead to improvements, will help us to provide a better service.

THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item was monitored and guided by the Stress Analysis and Strength of Components Committee, which first met in 1964 and now has the following constitution:

Chairman	
Mr J.V. Vint	— C.A. Parsons and Company Ltd
Vice-Chairman	
Mr H.L. Cox	— Independent
Members	
Mr A.J. Batchelor	— Imperial Chemical Industries Ltd
Mr C.E. Day	— Independent
Dr R.B. Heywood	— A. Macklow-Smith Ltd
Mr M.J. Kemper	— A.P.V. Company Ltd
Dr L.C. Laming	— Imperial College of Science and Technology
Dr R.M.G. Meek	— National Engineering Laboratory
Mr G.P. Smedley	— Lloyd's Register of Shipping
Dr J. Spence	— University of Strathclyde
Dr C.E. Turner	— Imperial College of Science and Technology.

The Item was accepted for inclusion in the Fatigue – Endurance Data Series by the Fatigue Committee, which first met in 1955 and now has the following constitution:

Chairman	
Mr W.T. Kirkby	— Royal Aircraft Establishment
Vice-Chairman	
Mr K.E. Cheverton	— Rolls-Royce (1971) Ltd, Bristol Engine Division, Filton
Members	
Mr R.A. Clare	— Procurement Executive, Ministry of Defence
Mr H.L. Cox	— Independent
Mr A.J. Fenner	— Independent
Mr A.D. Hall	— Westland Aircraft Ltd
Dr W.J. Harris	— Rolls-Royce (1971) Ltd, Small Engine Division, Leavesden
Mr J.A.B. Lambert	— Hawker Siddeley Aviation Ltd, Hatfield
Mr N.H. Mason	— Consulting Engineer
Mr H.E. Parish	— British Aircraft Corporation Ltd, Preston
Mr J.B. Sanders	— Procurement Executive, Ministry of Defence

(Continued on inside back cover)

THE EFFECT OF SURFACE ROUGHNESS ON THE FATIGUE LIMIT OF STEELS AT ZERO MEAN STRESS

CONTENTS

	Page
1. NOTATION	1
2. NOTES	1
3. PEAK-TO-VALLEY HEIGHT OF SURFACE ROUGHNESS R_t	2
3.1 Measurement of r_t	2
3.2 Interpretation of Surface Roughness Measurements	3
4. DERIVATION	3
5. EXAMPLES	5
5.1 Example 1	5
5.2 Example 2	6
6. SECTIONS THROUGH MACHINED AND POLISHED SURFACES	7
APPENDIX A CENTRE-LINE-AVERAGE MEASUREMENT OF SURFACE ROUGHNESS	12
A1. INTRODUCTION	12
A2. NOTATION	12
A3. CENTRE-LINE-AVERAGE HEIGHT	12
A4. TYPICAL SURFACE ROUGHNESS VALUES	13

THE EFFECT OF SURFACE ROUGHNESS ON THE FATIGUE LIMIT OF STEELS AT ZERO MEAN STRESS

1. NOTATION

f_t	tensile strength	N/m ²	lbf/in ²
k_{sf}	surface finish factor due to surface roughness defined by $K_{sf} = \frac{S_{p0}(\infty)}{S_{a0}(\infty)}$		
L	surface roughness sampling length	m	in
r_a	centre-line-average height of surface roughness	m	in
r_t	peak-to-valley height of surface roughness	m	in
r_{t0}	peak-to-valley height of surface roughness below which no improvement in fatigue strength can be made	m	in
$S_{a0}(\infty)$	fatigue limit alternating stress at zero mean stress with surface roughness depth less than r_{t0}	N/m ²	lbf/in ²
$S_{p0}(\infty)$	fatigue limit alternating stress at zero mean stress with surface roughness depth greater than r_{t0}	N/m ²	lbf/in ²

Both SI and British units are quoted.

2. NOTES

This Item provides data on the zero mean stress fatigue limit of steels having rough surfaces. There is a variety of methods in use for the description of surface roughness; however, the peak-to-valley height measure is the most pertinent to fatigue situations and is used throughout this Item. Other methods and conversion to peak-to-valley height are discussed in Appendix A.

All steels contain minute flaws, the critical size of which decreases as the material tensile strength increases; consequently, reduction of surface roughness, r_t , to less than this flaw size produces no further improvement in fatigue limit. This cut-off value of surface roughness is denoted by r_{t0} . At roughness levels below r_{t0} failure will occur from these inherent flaws.

The data are presented in Figure 1 in terms of k_{sf} plotted against r_t for a range of values of tensile strength. The form of the curves was decided not only by the data shown but also by the trends indicated by the available qualitative data. There will be scatter about these lines for which, in critical situations, an allowance should be made. Figure 2 is derived from Figure 1 and presents the curves alone up to a roughness of r_t equal to 500 μm (2×10^{-2} in). Also in Figure 2 are presented lines of constant $k_{sf} f_t/2$ for design purposes. Figure 3 shows a curve of f_t against r_{t0} , the surface roughness cut-off value, to enable the user to check quickly to see whether or not surface roughness effects are significant. This curve was obtained

Issued November 1974

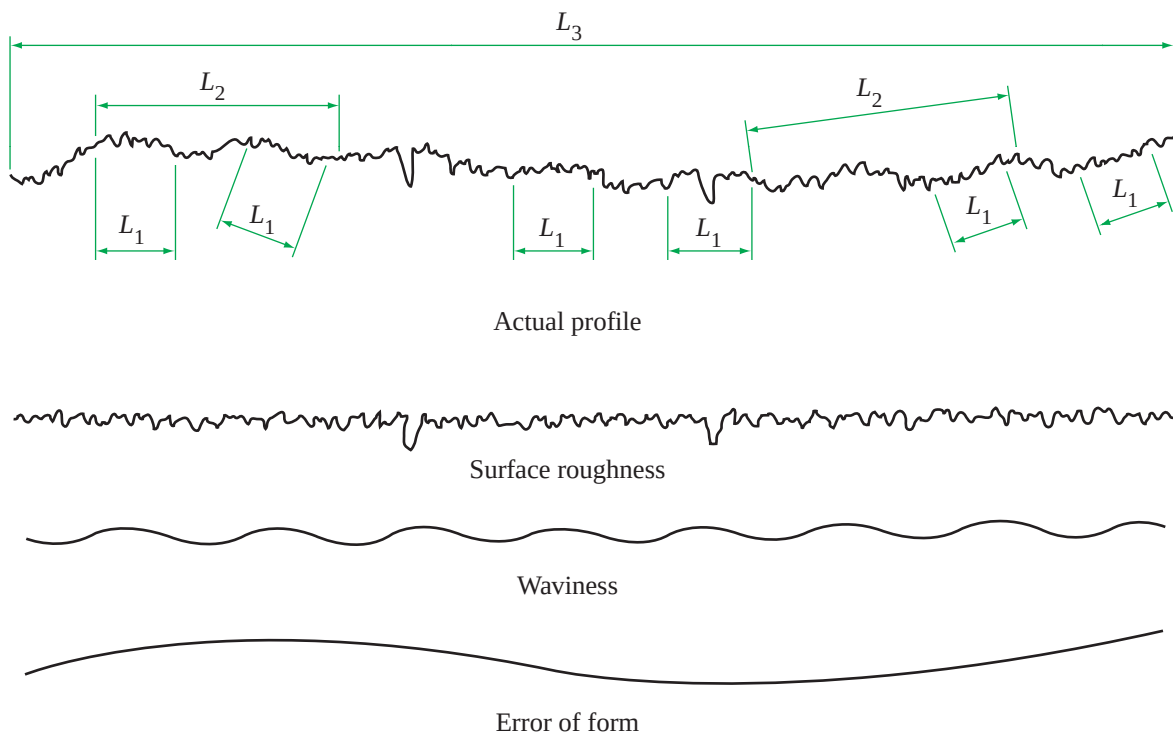
from Figure 1 by cross-plotting values at $k_{sf} = 1.0$. A line obtained by cross-plotting for values of $k_{sf} = 0.95$ is also given on Figure 3. Figure 4 is a cross-plot of Figure 1 with k_{sf} plotted against f_t for a series of values of r_t .

3. PEAK-TO-VALLEY HEIGHT OF SURFACE ROUGHNESS r_t

3.1 Measurement of r_t

Sketch 3.1 illustrates a section through a typical machined surface magnified many times. It appears as a rough terrain of peaks and valleys. The surface undulations can be broken down into two textures superimposed upon an error of form. The primary texture, or surface roughness, is produced, for example, by the effect of the tool, by abrasions or by metallurgical structure factors. Secondary texture, or waviness, results from eccentricity or misalignment of the production apparatus used.

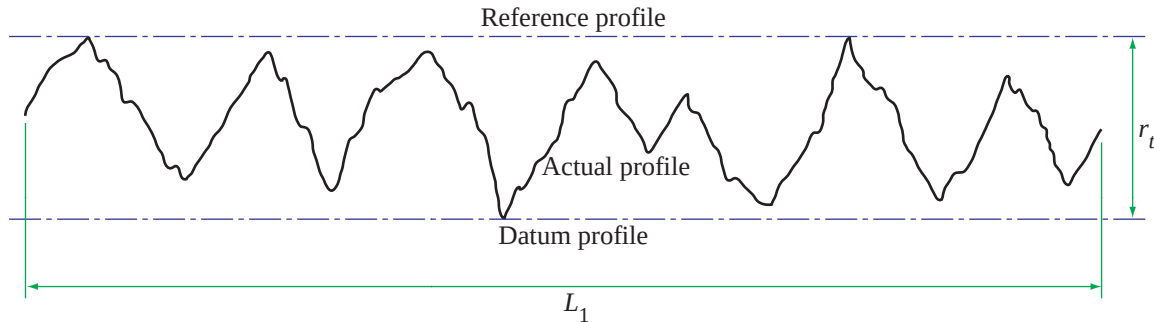
Choice of sampling length (the length of surface examined by, for example, a stylus) is important. If a sampling length L_3 is chosen, as shown in Sketch 3.1, the effects of error of form will be seen as well as those of waviness and surface roughness. If a sampling length of L_2 is chosen, only waviness and surface roughness will be recorded. If a sampling length of L_1 is taken, then the effects of error of form and waviness will be negligible and a reasonably accurate surface roughness trace will be found. A series of traces of sampling length L_1 must be taken to ensure representative results. Taking L_1 equal to 0.8 mm will give satisfactory results for most practical engineering surfaces (see Derivation 13).



Sketch 3.1 Characteristics of a machined surface

The peak-to-valley height of surface roughness is determined as shown in Sketch 3.2. The distance r_t is the maximum vertical deviation of the actual profile from the reference profile. The reference profile is a line that touches the highest peaks within the sampling length. This line is straight for short sampling lengths but may have the form of the geometrically ideal profile or may follow periodicity in the surface. The datum profile is a line parallel to the reference profile that just touches the lowest valley within the sampling length.

The value of surface roughness that is of interest is that normal to the direction of applied stress. In combined stress situations it may be necessary to take traces in several directions to ensure that the value of r_t used is the maximum.



Sketch 3.2 Measurement of peak-to-valley height of surface roughness

3.2 Interpretation of Surface Roughness Measurements

Table 6.1 shows several sections through machined and polished surfaces. Cases a, b, c and d show profiles of turned surfaces and e, f, g and h show profiles of ground, lapped, hand polished and scored surfaces respectively. These surfaces assume improvement of surface texture by the use of progressively finer techniques. From these profiles it can be seen that different topographies may produce similar r_t values. A local scratch in an otherwise flat surface may give the same r_t value as an overall rough surface. Cases b and c, although nominally produced by the same method, show different surface roughnesses. This emphasises the danger of classification of surfaces by production method and illustrates one reason for scatter observed in surface roughness effects. The production process may induce residual stresses in the material which can have a pronounced effect on the fatigue limit. These stresses are, however, usually compressive and improve the fatigue properties of the material.

Defects that have been smeared over or surface cracks produced by careless grinding will not show up on profile traces. Such defects may lead to premature fatigue failure especially in the higher strength steels.

4. DERIVATION

1. NIEMAN, G.
GLAUBITZ, H. Einfluss der Oberflächenrauheit auf die Biege-Wechselfestigkeit von ungehärtetem und vergütetem Stahl. *Z. ver. dt. Ing.*, Vol. 94, No. 25, pp. 855-857, September, 1952.
2. SIEBEL, E.
GAIER, M. Untersuchung über den Einfluss der Oberflächenbeschaffenheit auf die Dauerschwingfestigkeit metallischer Bauteile. *Z. ver. dt. Ing.*, Vol. 98, No. 30, pp. 1715-1723, October, 1956.

Translation available as "The influence of surface roughness on the fatigue strength of steels and non-ferrous alloys", *Engrs Dig.*, Vol. 18, No. 3, pp. 109-112, March 1957.
3. FROST, N.E. A relation between critical alternating propagation stress and the crack length for mild steel. *Proc. Instn Mech. Engrs*, Vol. 173, No. 35, pp. 811-836, 1959.