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INFLUENCE OF MICROGEOMETRY OF SURFACES ON THE CONTACT APPROACH OF ELEMENTS WITH A SURFACE LAYER

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Effects on the microgeometry of surfaces on the contact approach of steel elements of joints at rest are investigated in the paper. A case of elements with nominally flat surfaces subjected to quasi-statical load is considered. The results of experiments are presented made with the use of an original device for studying contact phenomenon, designed and constructed in the Institute of Fundamental Technological Research of PAS (IPPT PAN). It is shown to what extent the contact approach depends on the microgeometry of a surface obtained in the machining process.

1. INTRODUCTION

Contact joints constitute indispensable elements of almost every machine or other mechanical devices. Their character results from certain requirements which can be satisfied by the state of the prepared surface layer of the elements brought to contact. The state of the surface layer mainly depends on the physical properties of the considered material and the geometrical properties of its surface. These properties exert an influence on the lubricity of the surface, contact stiffness, dynamics, vibrations as well as heat exchange and electrical conductivity of particular connections and the whole mechanical systems. Many situations exist in which specific operation requirements have to be satisfied such as tolerance of fit. In these cases the knowledge of mechanical properties of elements with surface layer turns out to be essential [1, 2]. Due to the cost of practical and theoretical investigations, suitable experiments are made only in exceptional situations. In the presented paper a small step towards better understanding of the problem of contact approach of elements of joints at rest is made.

2. AIM AND SCOPE OF INVESTIGATIONS

The paper is aimed at demonstrating an effect of the microgeometry of surfaces on the contact approach of elements with a surface layer. Nominally flat elements of the same grade of steel and machined by the typical mechanical processes are studied. As known, the value of contact approach depends on the geometrical texture of surface and the mechanical properties of surface layer. To analyse effects of microgeometry on the contact approach the experimental investigations should refer to specimens whose surface layers have the same mechanical properties. That is why the same grade of steel was used to prepare the testpieces. The specimens were annealed in the vacuum to remove the changes of mechanical properties caused by machining and, at the same time, retaining the differences in the geometrical texture of the surfaces.

The changes of contact approach are observed during quasi-statical loading of a real surface of the element under consideration by means of an ideally smooth and rigid counter-surface of a second element. An actual influence of surface layer on the contact approach of the element under applied load was attempted to be disclosed. Topographically different surfaces were studied subjected to nominal loads that exerted stresses larger than the yield point of the material.

3. THE METHOD AND THE MEASURING DEVICE

The applied measurement method of the contact approach and the device itself make it possible to observe changes in the approach during increasing applied load. The obtained results refer to a nominally flat element brought into contact with an ideally flat and rigid elements. This basic configuration is usually employed in the studies of contact mechanics [1–5], see Fig. 1.

In the conventional measurements of the surface approach the latter is assumed to be a sole result of the deformations of microroughnesses of the surfaces due to loading. Under such an assumption the test results were compared with the mathematical modelling results and the discrepancies were explained as an outcome of inadequate theoretical models, [1, 6]. Without disagreeing with certain criticism, it has been ascertained that a considerable amount of responsibility for those discrepancies lies in the interpretation of experimental results [4]. Measurement of the approach of two surfaces has

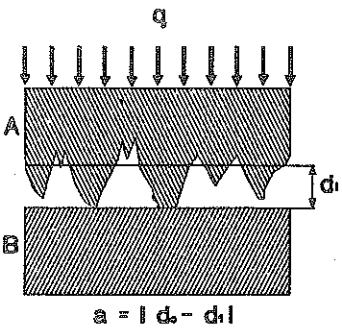

FIG. 1. Basic configuration to determine the relationship between the contact approach a and the applied nominal pressure q. A – tested element, B – ideally rigid and smooth counter-element.

been observed to be a result of both the deformations of microroughnesses and of a layer of material below the surface which is termed a bulk material. However, even the best test devices cannot eliminate a contribution of bulk material to the overall picture of the approach. A special elimination procedure was devised and described by the authors of [4]. An idea behind this elimination procedure is visualized in Fig. 2.

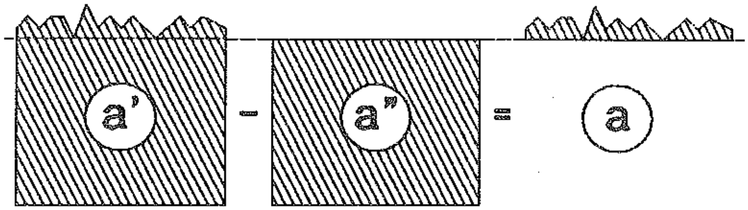

FIG. 2. A concept how to eliminate contribution of bulk material in the process of contact approach. a' – contact approach allowing for its roughness, a'' – neglecting roughness, a – as a result of roughness only.

It consists in considering the relationship between the approach and the applied load $a''(q)$ associated with an ideally smooth element as a characteristic of the bulk material. Its knowledge makes it possible to difference-wise eliminate the contribution of the bulk material from the measurement of the approach of the surface of an element with the microroughnesses $a'(q)$. Thus the obtained characteristic $a(q)$ enables to analyse an effect of microgeometry on the contact approach of elements with a surface layer.

A specially designed measuring device to study changes in the contact approaches as functions of the load applied was described in detail in [4].

The operation of the device consists in the use of the following measurement techniques: Demkin's method [8], the induction measurement of the displacements associated with the investigated approach and the procedures of resistance strain gauge method with the use of the force transducer to determine the applied pressure q. The device was designed in the IPPT PAN and its feature is to register automatically the results as measurements go and their immediate processing afterwards. The experiments can be carried out for an arbitrarily chosen interval of loading from the range $0 - 1000\,\mathrm{MPa}$ and for actual approaches from 0 to $200\,\mu\mathrm{m}$. The errors depend on the choice of measurement range; for the widest range possible they can amount to $\pm 10\,\mathrm{MPa}$ and $\pm 0.5\,\mu\mathrm{m}$.

As mentioned before, a quasi-flat specimen denoted by A in Fig. 1 is brought into contact with the surface of "ideally smooth and rigid" counter-specimen B. The latter's hardness is equal to 63 HRC and smoothness $R_a = 0.08\,\mu\mathrm{m}$. The element B is made as a ring with three sectors, each having a nominal contact area $200\,\mathrm{mm}^2$. Such a shape of specimen makes it possible to take three measurements by using one testpiece. The changes in contact area are made by a rotation of the cylindrical specimen A by 120° with respect to the reference specimen B.

4. TEST AND DISCUSSION OF RESULTS

All the specimens were made of steel 45 and had the dimensions $\phi\, 46 \times 23\,\mathrm{mm}$. The surface layer was prepared with the use of three types of machining: turning, grinding and bead-blasting. To observe better the behaviour of surfaces, the microgeometry of the studied elements had rather large amplitudes ($R_a \geq 2.5\,\mu\mathrm{m}$). The tested elements are listened in Table 1 where the microgeometric parameters of surfaces are also given. These parameters are: R_a – arithmetic average roughness, R_{SK} – skew distribution of roughness with respect to the mean surface plane, R_p – maximum peak height above the mean plane, and R_t – maximum height of summit. The properties of surfaces were measured by a scanning profilometer enabling the three-dimensional description of the geometrical texture, unlike in the currently used profile characteristics.

Each designated surface consisted of three specimens prepared with the same type of machining. Thanks to the three sectors of each specimen, each series of measurements consisted of nine readings.

Table 1.

Designation of surface	Type of machining	Microgeometry of surface			
		R_a, µm	R_{SK}	R_p, µm	R_t, µm
T13	face turning	3.47	−0.20	17.60	32.00
T113		3.43	+0.01	20.80	36.80
T1113		3.32	+0.40	22.20	35.80
T16		3.46	+0.12	27.20	42.80
T116		3.79	+1.34	32.00	42.40
T1116		15.41	+1.24	125.00	165.00
T19		5.50	+0.38	42.80	60.00
T119		30.46	+0.98	138.00	196.00
T1119		53.84	+0.72	220.00	316.00
S	circumferential griding	2.72	−0.38	8.00	21.00
SS	bead-blasting	2.62	−0.17	8.00	21.00

The used parameters of maching are shown below.

SERIES T

1 advance 0.20 mm/rev., velocity of revolution 224 rev/min,
11 advance 0.35 mm/rev., velocity of revolution 280 rev/min,
111 advance 0.50 mm/rev., velocity of revolution 355 rev/min,
3 angle of cutter 30°, fillet radius: large L^*,
6 angle of cutter 60°, fillet radius: medium M^*,
9 angle of cutter 90°, fillet radius: small S^*.

Precise values of the fillet radii are not given due to measurement difficulties.

SERIES S

coked electrocorundum,
grinding wheel 99 A - 66 - 40M5,
$v = 35\,\mathrm{mm/s}$, $p = 1\,\mathrm{mm/pass}$.

SERIES SS

glass beads $\phi = 0.8\,\mathrm{mm}$,
pressure 2 atm,
distance of the nozzle 100 mm,
inclination of the nozzle 90°.

In order to determine the characteristics of the bulk material $a''(q)$, a specimen with precisely ground face surface was used, the relevant parameters being: $R_a = 0.18$, $R_{SK} = -0.10$, $R_p = 0.66$, $R_t = 2.27\,\mu\mathrm{m}$. Each number is an average taken from three independent measurements registered during the loading program from 0 to 600 MPa.

To visualize a role which the bulk material can play in the contact approach of elements having surface layers, two developments of the approach are depicted in Fig. 3: one for the specimen T16 ($a'(q)$) and another for its bulk material ($a''(q)$ compare Fig. 2). The observed difference in the diagrams demonstrates the approach caused only by the deformations of microroughnesses.

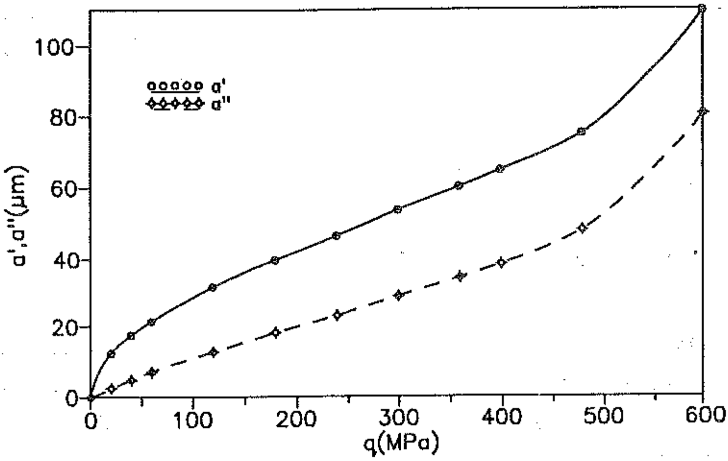

FIG. 3. Approach vs. applied presure for a rough surface $a'(q)$ and smooth surface $a''(q)$.

The measurements of approaches resulting solely from the presence of surface microroughnesses ($a(q) = a'(q) - a''(q)$) were carried out under pressures increasing quasi-statically from 0 to 600 MPa with the use of dial gauge with the range of $0 - 200\,\mu\mathrm{m}$. The errors did not exceed ± 5 MPa and $\pm 0.5\,\mu\mathrm{m}$, respectively.

Figures 4–6 shown the diagrammatic characteristics $a(q)$ for the surfaces turned with various advances. Each figure corresponds to different radius of rounding of the cutter.

Exemplary results for surfaces prepared with the same advance and three different cutters are seen in Fig. 7. Finally, Fig. 8 shows the results for surfaces of similar geometries prepared with the use of grinding and bead-blasting.

In each of the Figs. 3–7 a dashed line R can be seen that characterizes the bulk material $a''(q)$. Attention is thus drawn to the proportions of

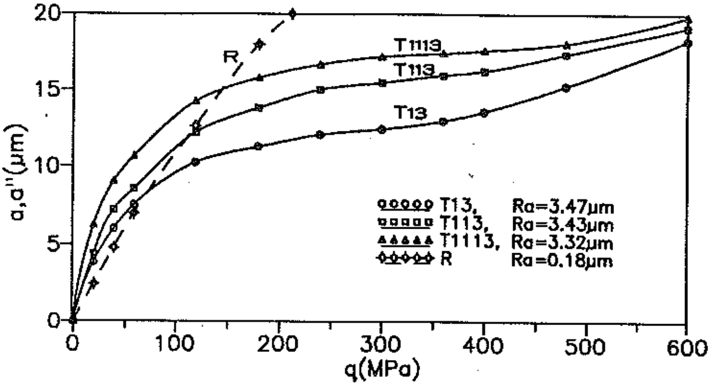

FIG. 4. Diagrams $a(q)$ for face turned surfaces T13, T113, T1113. R – characteristics of bulk material $a''(q)$.

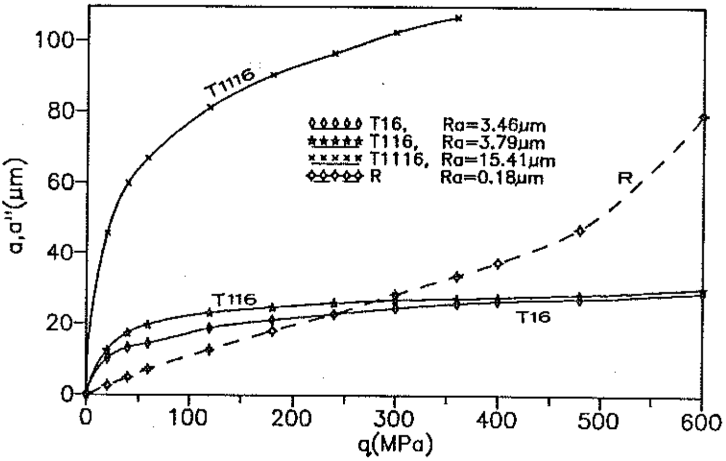

FIG. 5. Diagrams $a(q)$ for face turned surfaces T16, T116, T1116. R – characteristics of bulk material $a''(q)$.

influences of the bulk material and the microgeometry of surface on the contact approach of an element with a surface layer.

At the initial stage of loading of an arbitrary element the approach is first of all a result of the deformations of micro-roughnesses. It can be easily seen that the approach corresponding to loading range is wider when the parameters of the surface amplitudes are larger. Plastic deformations of roughnesses cause certain changes in their mechanical properties (strain-hardening of the involved material) and further development of contact phenomena becomes even more complicated.

Separate analyses of Figs. 4–8 lead to the following conclusions:

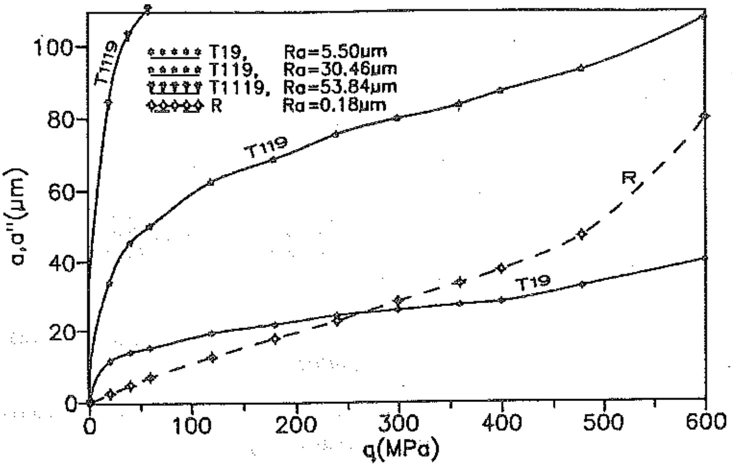

FIG. 6. Diagrams $a(q)$ for face turned surfaces T19, T119, T1119. R – characteristics of bulk material $a''(q)$.

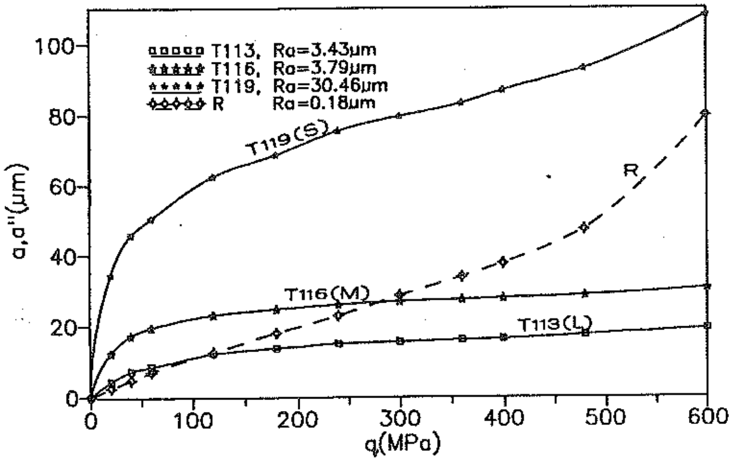

FIG. 7. Diagrams $a(q)$ for face turned surfaces T113, T116, T119. R – characteristics of bulk material $a''(q)$.

FIGURES 4–6 (see also Table 1)

Deformations of contact area depend on the advance of the cutter and grow with its increase. This fact can be explained by the increasing amplitudes of roughness and a decrease of the density of contact areas due to growing advance.

In the everyday structural practice one parameter for the description of the surface, e.g. R_a is used and the machining technique is seldom indicated.

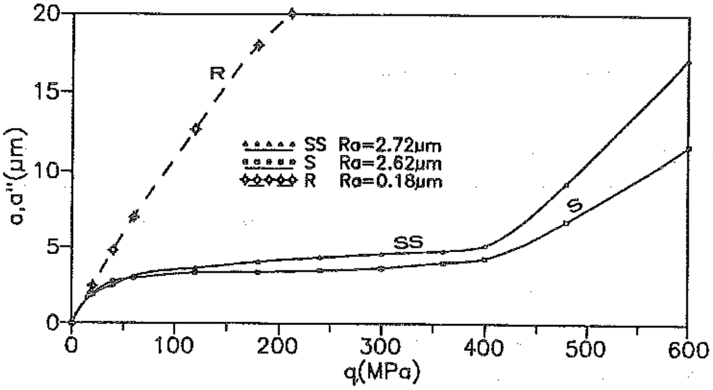

FIG. 8. Diagrams $a(q)$ for the circumferentially ground surfaces S and the bead-blasted surfaces SS. R – characteristics of bulk material $a''(q)$.

These data are insufficient to evaluate precisely the contact approach (see Figs. 4–7).

FIGURE 7

The diagrams show an influence of wear of the cutter on the micro-geometry of the surface. At the same advance the contact approach increases with decreasing radius of the rounding of the cutter or, in other words, with increasing amplitudes of the surface roughness. The nominal angle of the cutter is here of secondary importance (compare also Figs. 5 and 6).

FIGURE 8

Here a case of surfaces having almost identical roughness parameters but prepared with the use of different tools is illustrated. The discrepancies of the characteristic diagrams can be explained by the values of the parameter R_{SK}, see also the second remark referring to Fig. 4. It shows again how inadequate it is to describe the microgeometry of the surface by means of commonly used parameters such as R_a which in reality do not characterize the effects of topography of the surface on the contact-approach.

5. Conclusions

Certain changes in the contact approach of nominally flat elements of joints at rest, made by means of various machining techniques, have been investigated. The tests show the important effects of the microgeometry of contacting surfaces on the approach of elements of joints. Attention is drawn to the influence of the method of machining elements on the contact and the difficulties in the evaluation of the approach with the use of a basic parametric description of roughness. The presented method to eliminate a contribution of the bulk material in the contact processes makes it easier to study the approaches as a sole result of the state of a surface layer. The presented results are of a cognitive value. A part of them refer to smoother surfaces used in various joints and seals and even in some guides and transmission gears [8].

It is planned to extend the analyses of contact approaches by allowing for multiple contact pressures.

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