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UTILIZATION OF THE DESIRED MACHINED SURFACE ROUGHNESS NUMBER AS A CRITERION FOR CUTTING TOOL REPLACEMENT STRATEGY

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ABSTRACT

Current research in metal removal processes does not provide predictive relationships vitally needed for the selection of machining conditions or specifying limitations on the cutting tool and work material responses. Efforts in the study of tool wear have not progressed to the point that tool life can be predicted using tool and work material properties through fundamental science and engineering principles. Tool replacement decisions are dependent on sensing the wear on the tool or predicting its magnitude by empirical models. This study is an attempt to establish a tool replacement strategy that optimizes a selected performance objective. A quantitative model is presented to experimentally predict the roughness number of the machined surface from the flank wear value of the cutting tool in a turning application then to use it to develop a tool replacement strategy based on the desired machined surface roughness number as a tool failure criterion. Results prove that there is a distinct mathematical relation that ties the tool flank wear value to the resulting roughness number of the machined surface irrespective of the cutting conditions.

INTRODUCTION

Metal removal processes lack adequate quantitative characterization. This presents a major constraint on the cutting process design, planning, optimization and control. The importance of transforming the metal cutting industry from "experience-based" to "knowledge and data-based" has become more evident with the introduction of Computer Aided Manufacturing.

Since the development of the first empirical tool life model by F.W. Taylor in 1906, several different phenomenological approaches have been tried for the development of usable quantitative characterization of the metal removal process (6). Among some of the significant approaches tried have been:

— Mechanics of chips formation
— Plasticity analysis
— Thermal analysis

— Dislocation study of the shear zone
— Tool wear theories

Each of these approaches has produced useful information, however-given the work material, the cutting tool, and the operating conditions - *none has been able to produce a theory or relationship that could be used to predict important machining responses such as tool life, machined surface finish and product dimensional accuracy (5).*

The empirical approach for quantitative characterization of the metal removal process is to develop a mathematical relationship between a machining response and the operating conditions directly through a set of experiments. The information gained through this approach provide valuable guidance for developing a phenomenological understanding of the process.

Although most models have been developed on the basis of laboratory tests, experimental data and practical applications are presently still lacking. One of the major difficulties in applying a phenomenological approach to metal removal processsses has been that the metal behavior relevant to a specific process can not be reproduced and studied except through actual tests.

Surface Roughness and Metal Removal Processes

Surface roughness consists of the fine irregularities in the surface texture including those resulting from the inherent action of the machining process (1). The most common methods of designating surface roughness are the arithmetic average (R_A) and the RMS value (R_Q) (2). The (R_Q / R_A) ratio varies with the machining process producing the surface (1.17 : 1.26 in turning). A variety of surface roughness values can be produced by both conventional and nonconventional metal removal techniques. Turning and milling process can produce surface roughness of around 3 μm (0.003 mm) while a very fine surface would require additional finishing operations resulting in increased cost (7).

Theoretical Surface Roughness Produced by Cutting Tools

Surface roughness calculations have been made for the most common cutting tool shapes. Relations of the theoretical surface roughness as a function of feed, nose radius, cutting edge angle, and the side edge angle have been established and documented (11). The theoretical surface roughness obtained from these calculations represent the best finish produced by the particular tool and process, thus, provides an indication of the minimum surface roughness possible with a designated tool shape and cutting conditions. The actual surface roughness may be poorer because the surface is further degraded by a build-up edge or the wear of the cutting edge that produces the finished surface.

Characteristics of the Metal Removal Process and Tool Wear (3)

The basic characteristics of the metal removal process can be described schematically as shown in Fig. 1. Metal removal is achieved through intense shear deformation at the shear plane "4". The tool wear occurs along the cutting edge and on adjacent surfaces. It is localized on specific surfaces where stress, strain, velocity and temperature are above critical limits. Along the rake surface, the chip motion and normal stress produce a wear scar called the crater wear "1". Along the clearance surface, the tool motion and high normal stress increase the area of contact producing the flank wear "3". The cutting edge radius increases as a result of edge wear "2" and often a built-up edge "5" is formed. (4, 8, 10) The figure shows how the wear process changes the geometry of the sharp cutting tool. While the edge and crater wear-on the rake surface-alter the state of stress and strain in the cutting region changing the cutting forces and mechanics of chips formation, the flank wear decreases the depth of cut and would produce out-of-tolerance dimensions on the machined part. It is belived that flank wear, edge wear, and the unstable built-up edge, are the prime causes of poor surface finish. Excessive wear - in general - results in an unacceptable surface finish and/or out of tolerance part dimensions.

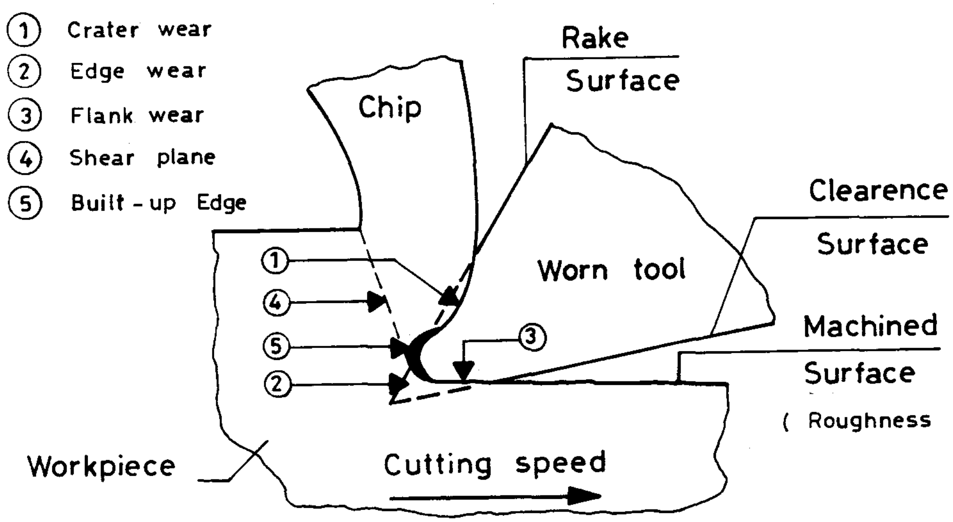


Fig. 1: Schematic representation of the characteristics of the metal removal process.

Cutting Tool Replacement Strategy and Tool Wear Modeling

This study develops a tool replacement strategy that optimizes the tool performance represented by the roughness number of the produced surface. *The strategy depends on the assumption that there is a distinct mathematical relation* *that ties the tool flank wear value (W) to the resulting roughness number (R) of the machined surface irrespective of the cutting conditions.*

Tool wear has been established to depend on cutting velocity where the equation ($VT^n = c$) was developed using data from tool life tests (12). This is known as Taylor's tool life equation in which the tool life time (T) is related to the cutting velocity (V) by means of the constants (n) and (c) obtained by testing tools at different velocities and using a tool life criterion to establish the point at which the useful life of the cutting tool has ended. This criterion has been a wear limit that could not be exceeded to avoid tool failure (14). Fig. 2a shows typical tool wear time curves for different velocities (9). The wear limit or failure criterion shows that the elapsed time before tool replacement decreases with increasing velocity. Taylor's relationship models this behavior and has been used in industry as originally conceived or in modified forms up to the present time.

Establishing the Machined Surface Roughness as a Tool Failure Criterion

Setting the wear limit or failure criterion is an important and critical decision to be made in the process of developing a tool life mode. However, failure consequences can instead depend on the type of another selected feature or quality associated with the cutting process. *This study assumes the roughness number of the machined surface to be the established criterion for setting a limit on the flank wear value of the cutting tool and, consequently, identifying its tool life and replacement time.* To access failure even while meeting the roughness criterion, tool wear must be mathematically related to the roughness number of the machined surface (13). Fig. 2b assumes a theoretical relation between the cutting tool flank wear (W) and the corresponding machined surface number (R); a relation that could be experimentally obtained.

Procedure for Tool Replacement Strategy

The following is a recommended procedure for utilizing the machined surface roughness as a criterion for cutting tool replacement strategy:

1. Develop-experimentally - the tool flank wear-time curves at different cutting speeds as in Fig. 2a.

2. Measure and record the roughness number of the machined surface at different cutting time intervals.

3. Plot the values of flank wear (W) against the measured roughness number (R) and construct the resulting relation $W = f(R)$ as shown in Fig. 2b.

4. Select a limit value for the maximum acceptable roughness number (R_l) for a surface to be machined.

5. From the constructed curve, obtain the corresponding flank wear limit value (W_i) on the cutting tool.

6. On the wear-time curves Fig. 2a, select a cutting velocity (V_i), identify the wear limit and get its corresponding Tool Replacement Time (T_i), which guarantees a machined surface roughness not exceeding (R_i).

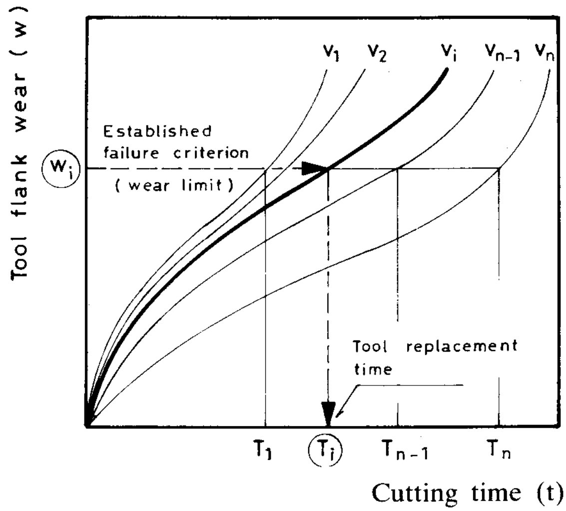


Fig. 2a: Typical cutting tool flank wear-time relation.

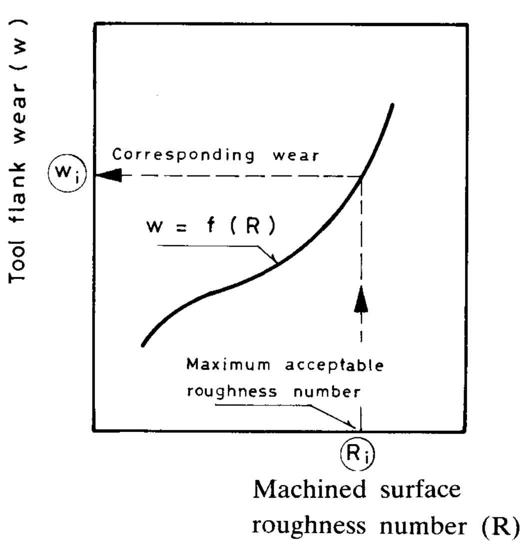


Fig. 2b: The assumed theoretical wear-roughness relation.

Fig. 2: Cutting tool replacement strategy concept.

EXPERIMENTAL RESULTS

According to the recommended procedure, experiments were conducted using a VALENITE CCMT 32.51-1A insert turning A1S1 1060 steel. Cutting speeds were selected to be 70, 120, 185 m/min with a depth of cut of 2.0 mm and a feed rate of 0.5 mm/rev. The three flank wear-time curves shown in Fig. 3 have been developed and constructed. The flank wear values were measued using a tool maker's microscope and the surface profile and parameters shown in Figs. 4, 5 & 6 were recorded at three different points on each curve using a Talysurf-5 system.

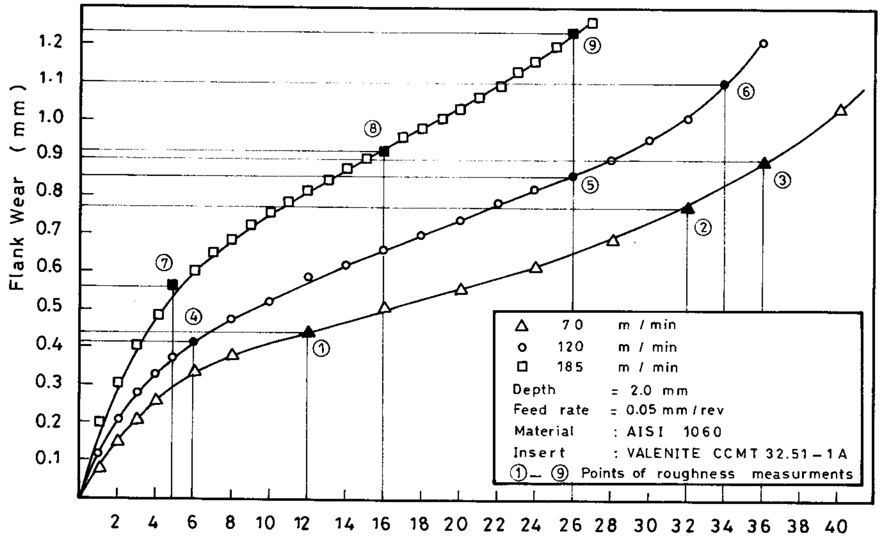


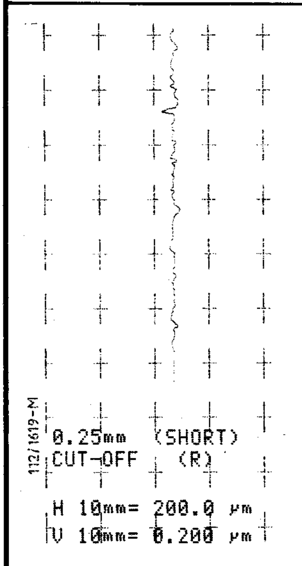
Fig. 3: Flank wear-time relation.

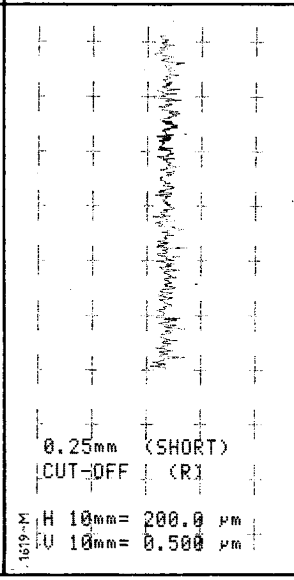
DISCUSSION AND CONCLUSION

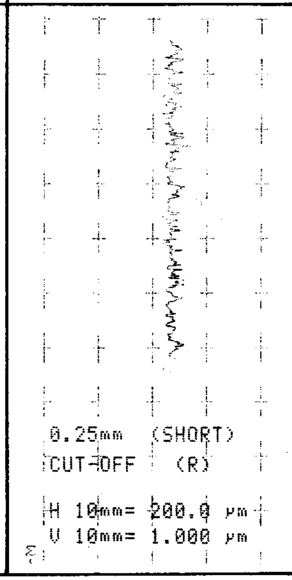
The measured flank wear values were plotted against their corresponding roughness numbers (R_A) and (R_Q) in Fig. 7. The results show a *distinct mathematical relation between the cutting tool flank wear value (W) and the resulting roughness numbers (R_A) and (R_Q) of the machined surface in turning.*

It is observed that the roughness numbers (R_A) and (R_Q) increase gradually with the development of the flank wear land W irrespective of the cutting speed. The results conclude that for a desired roughness number of the surface to be machined, a corresponding and unique flank wear value is easily identified and used as an established failure criterion for the cutting tool. Therefore, a cutting tool replacement time based on the roughness of the surface to be machined could be specified.

Cutting time = 12 min	Cutting time = 32 min	Cutting time = 36 min
Tool wear = 0.43 mm	Tool wear = 0.77 mm	Tool wear = 0.88 mm







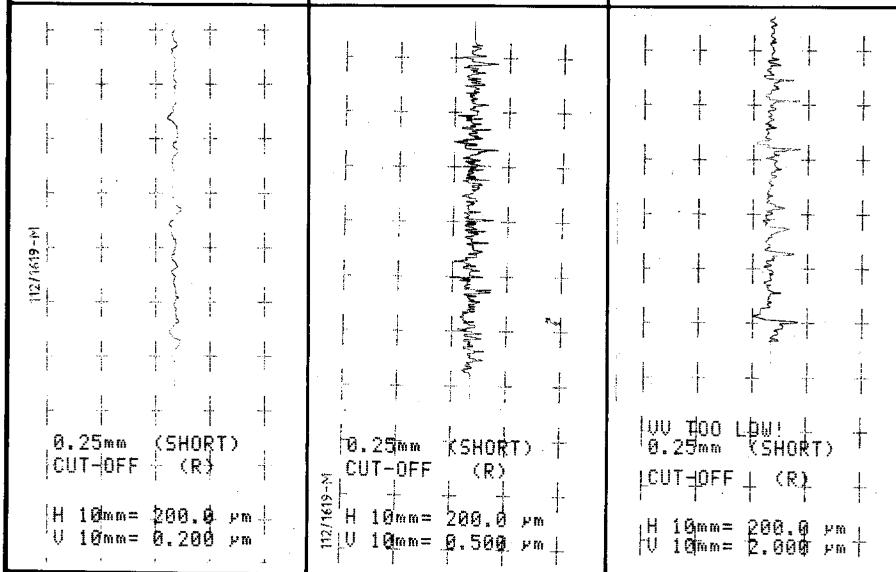
Surface profile

Parameter	12 min	32 min	36 min
HSC	8	69	31
SM	145.0 µm	17.74 µm	38.13 µm
λQ	21.89 µm	14.20 µm	17.59 µm
ΔQ	0.003	0.031	0.038
RMAX	0.078 µm	0.430 µm	0.668 µm
R3TM	0.036 µm	0.297 µm	0.414 µm
RTM	0.052 µm	0.381 µm	0.552 µm
RP	0.055 µm	0.186 µm	0.259 µm
RT	0.086 µm	0.449 µm	0.674 µm
RSK	-0.400	-0.606	-0.850
RQ	0.010 µm	0.070 µm	0.105 µm
RA	0.007 µm	0.055 µm	0.082 µm
	0.25mm (SHORT) CUT-OFF (R)	0.25mm (SHORT) CUT-OFF (R)	0.25mm (SHORT) CUT-OFF (R)

Surface parameters

Fig. 4: Data of the machined surface at a cutting speed of 70 m/min, feed rate = 0.05 mm/rev., depth = 2 mm.

	Cutting time = 6 min	Cutting time = 26 min	Cutting time = 34 min
	Tool wear = 0.41 mm	Tool wear = 0.85 mm	Tool wear = 1.10 mm



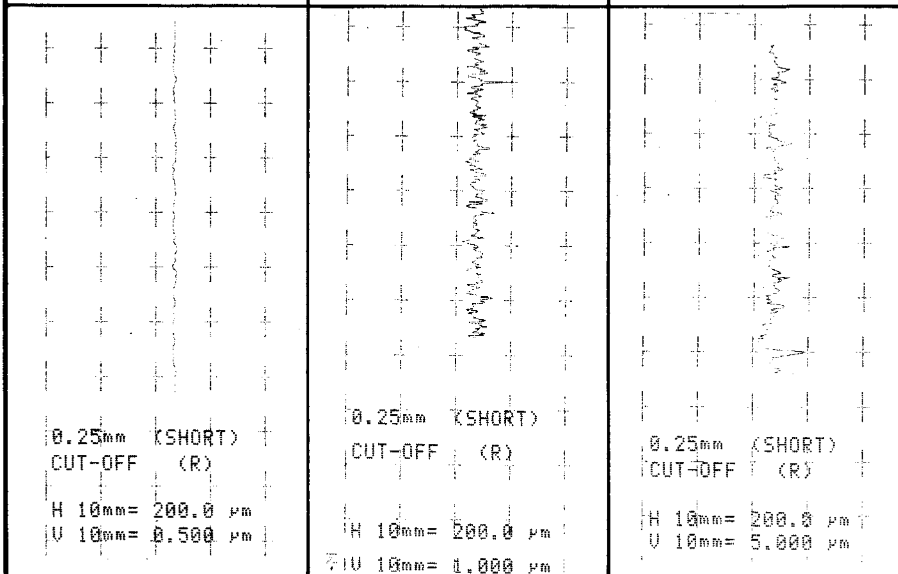
Surface profile

Parameter	6 min	26 min	34 min
HSC	8	72	25
SM	136.0 µm	17.25 µm	49.51 µm
λQ	26.74 µm	14.41 µm	22.88 µm
ΔQ	0.003	0.032	0.069
RMAX	0.064 µm	0.537 µm	1.828 µm
R3TM	0.036 µm	0.322 µm	0.641 µm
RTM	0.050 µm	0.448 µm	1.513 µm
RP	0.032 µm	0.303 µm	0.742 µm
RT	0.067 µm	0.599 µm	1.035 µm
RSK	0.305	-0.257	-0.949
RQ	0.011 µm	0.074 µm	0.251 µm
RA	0.008 µm	0.057 µm	0.182 µm
	0.25mm (SHORT) CUT-OFF (R)	0.25mm (SHORT) CUT-OFF (R)	VV TOO LOW! 0.25mm (SHORT) CUT-OFF (R)

Surface parameters

Fig. 5: Data of the machined surface at a cutting speed of 120 m/min, feed rate = 0.05 mm/min, depth = 2 mm.

Cutting time = 5 min	Cutting time = 16 min	Cutting time = 26 min
Tool wear = 0.56 mm	Tool wear = 0.92 mm	Tool wear = 1.23 mm



Surface profile

	5 min	16 min	26 min
HSC	1	39	19
SM	840.0 µm	31.17 µm	56.53 µm
λQ	23.16 µm	17.19 µm	29.17 µm
ΔQ	0.004	0.044	0.137
RMAX	0.069 µm	0.838 µm	4.508 µm
R3TM	0.043 µm	0.445 µm	1.562 µm
RTM	0.061 µm	0.665 µm	3.888 µm
RP	0.039 µm	0.334 µm	1.563 µm
RT	0.078 µm	0.898 µm	4.507 µm
RSK	0.753	-0.684	-0.768
RQ	0.014 µm	0.120 µm	0.637 µm
RA	0.012 µm	0.090 µm	0.470 µm
	0.25mm (SHORT) CUT-OFF (R)	0.25mm (SHORT) CUT-OFF (R)	0.25mm (SHORT) CUT-OFF (R)

Surface parameter

Fig. 6: Data of the machined surface at a cutting speed of 185 m/min, feed rate = 0.05 mm/min., depth = 2 mm.

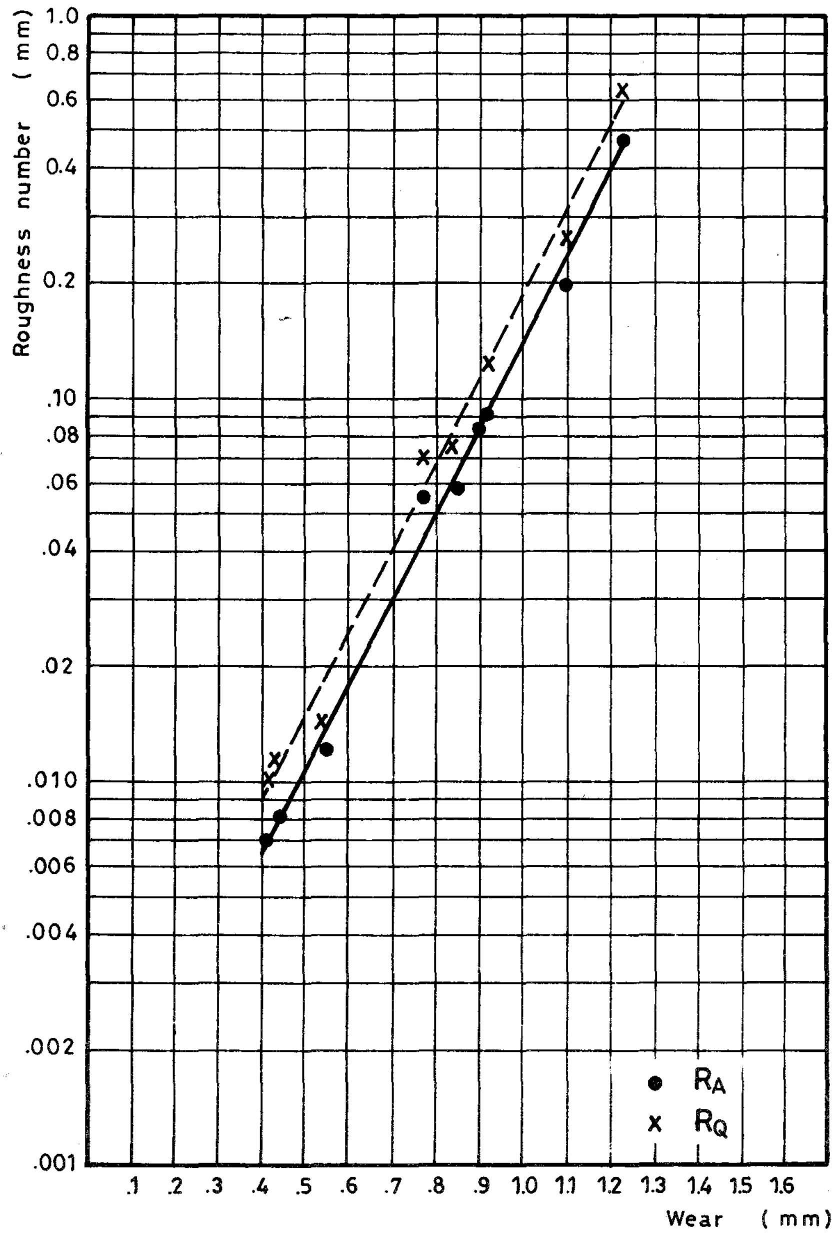


Fig. 7: Relation between the flank wear of the cutting tool and the roughness number of the machined surface.

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