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RESEARCH

Rapid investigation of materials machine ability in models condition using tribometer

Development of rapid model investigation and simulation of cutting process is result of intensive development of new materials and new tools with specific geometry made of new tool materials.
This work presents relatively simplified model of investigation caring out on tribometer „Block on Disk", where contact conditions over line is simulated, corresponding to contact between tool clearing face and machining surface of work piece. A block is made of material for cutting tool; a disc is made of material for work piece, while achieved contact conditions (normal loading and sliding speed) are meeting real working conditions.
Results of investigation presented in this paper shows that long-term and costly investigation of material machine ability with sufficient accuracy could be replaced with rapid model investigation on tribometer, and on the base of that information about material machine ability over tribological parameters (friction coefficient and wear scar on the block obtained by corresponded measurements on tribometer) could be obtained.

***Keywords**: friction coefficient, cutting inserts, tribometer*

1. INTRODUCTION

Development of new materials and improving of present materials are consequence of permanent striving to reduce losses of materials and energy produced by friction and wear into tribomechanical systems.

Rapid grow of automotive and airplane industry, rocket technique, energetic and processing industry and etc., cause a wide application of numerous types of new materials which satisfy specific exploitation conditions by its properties. These materials are high-alloy steels and stainless fireproof steels, carbon and alloy tool steels, special alloys on the base of nickel and cobalt, multilayer and ceramics materials, and etc. Majority of these new materials possess improved mechanical characteristics and specific physical properties which reduce their technology characteristics from the standpoint of forming and cutting process. That means that new materials are not hard workable only in machining, but almost in every type of processing. Problems of hard workable materials processing efficiency are still the subject of numerous research regarding continuous introduction of new materials, new procedures of its processing, new specialized cutting machines and new cutting tool materials.To fit hard work conditions, new materials have to be highly strength, heatproof and wear resistant.

It is not necessary to particular point out that in domestic industry tools made of high-speed cutting steel are still in use: HSS for low-speed cutting of easily workable materials and HSS.E with increased contents of alloys elements (W, Co, Mo) for hard-workable materials. Between hard metals (TM), TMs with coating and tungstenless TMs (cermet), which are distinguish with good ductility and strength of cutting edge, are in use.

The focus of this paper is the most used difficult to cut materials: high alloy tool steels, high alloy Cr-Ni steels and improved steels. Processing of these materials are specific regarding tool materials and geometry, cutting regime, cutting fluids, demands for raise machine stiffness, etc.

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Unavoidable need for rapid tribological models investigation is imposed by analyzing specific, variable processing conditions of difficult to cut materials, which require new types of tool materials and adapted tool geometry.

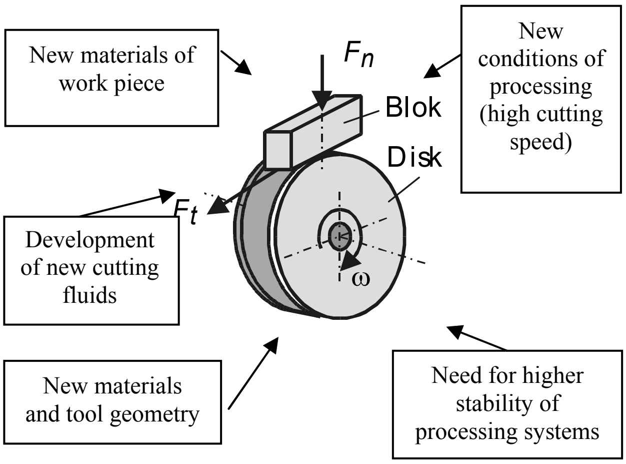

Figure 1: Requirements for rapid models investigations on tribometer.

Development of tribological measurement systems and methodology for models investigation enable simulation of cutting process on tribometer "Block on Disk" as well as identification of tribological processes into both of basic tribomechanics systems of this kind (Figure 2). That is concern on simulation of process happening into contact zone of tool insert rake face and chip, and tool clearing face and machining surface of work piece.

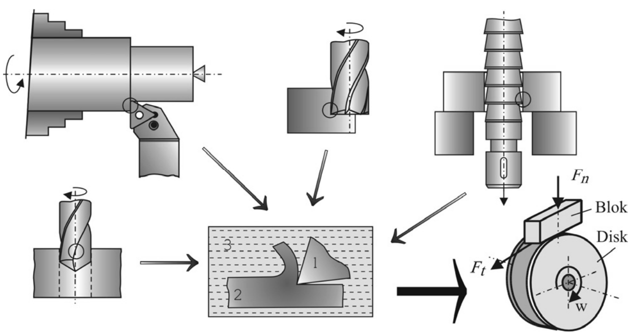

Figure 2: Main tribomechanical system in cutting process.

Investigations, begun with this aim and presented in this paper, are based on research of tribological phenomenon appearing in contact of two bodies (Block and Disk), while one body slides over another in presence of cutting fluid. Block is made of materials of cutting tool and disk is made of materials of machining work piece.

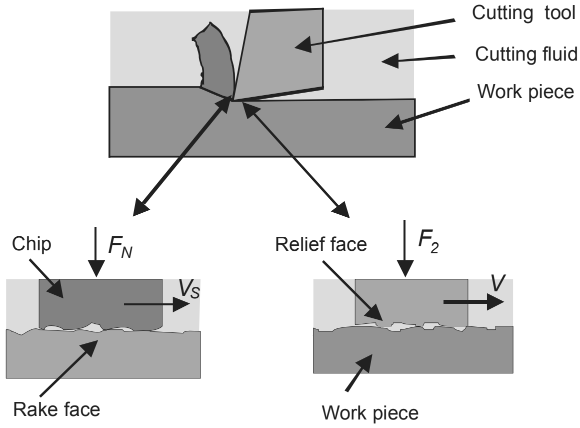

Figure 3. Basic tribomechanical system's in the machining process

A lot of efforts have been made and significant results accomplished in developing tribological methods and modern equipment for tribological investigations in the Laboratory for metal cutting and tribology at Faculty of Mechanical Engineering in Kragujevac for many last years. According that, several tribometers have been designed and developed.

2. PROGRAMS AND CONDITIONS OF EXPERIMENTAL INVESTIGATIONS

With the aim to investigate machinability of different materials in concrete cutting process conditions, an experimental investigations were performed on lathe, with high-speed steels tools (HSS.E) and hard metal tools (TM), with and without cutting fluids. Values of each of three resulting cutting resistant components are measured for different cutting regimes during investigations, and curves of tools wear are formed too.

Investigation on tribometer "Block on Disk" are performed after investigation on the lathe. Blocks are made of high-speed steels (HSS.E) and hard metal (TM) for cutting tools, and disks are made of materials for work piece used in investigation conducted on lathe. During investigation conducted on tribometer, the data of coefficient of friction and wear of contact surface between block and disk are obtained.
These investigation were conducted with aim to establish possible relationship between results obtained in machine cutting process and results obtained in tribolocigal investigation on "Block on Disk" tribometer.

Conditions of Lathe Turning Investigation

- Investigated materials: group of difficult to cut materials: Č3840 (Merilo) 248 HB; Č4150 (OCR 12) 277 HB; Č5430 improved 40 HRC; Č5741 (Utop extra 1) 258 HB; Č7680 (HSS) 299 HB.
- Cutting tools:
  - high-speed tool steel - Č9780 (HSS.E): turning tool JUS ISO 10 (16x25x250 E18 Co10) with geometry: $\gamma=6^0$; $\alpha=8^0$; $\lambda=0^0$; $\chi=45^0$; $\chi_1=45^0$; r=1 mm.
  - *carbide tipped tool: tip:SPGR 120308 PGP-135 (P35), PP CORUN; tool support: CSDRP 2516 M12, KENAMETAL.*
- Machine: universal turning lathe, 10 kW.
- Cutting fluid: cutting oil ISO 22
- Investigation regimes with HSS.E tool: cutting depth 0.5 mm; feed 0.112 and 0.14 mm/rev; cutting speed 20 and 40 m/min.
- Investigation regimes with hard metal tool (TM): cutting depth 0.5 and 1 mm; feed 0.14, 0.18 and 0.25 mm/rev; cutting speed 60 and 100 m/min.
- Measurement equipment: three-component dynamometer KISTLER, amplifier KISTLER, AD converter Burb Brown and computer.

Conditions of Tribometer Investigations

- Block materials: high-speed steel Č9780 (HSS.E) of hardeness 66 HRC; carbon tip without coating (TM) – SNUN 120412 in quality P30.
- Disk materials: group of difficult to cut materials investigated on lathe.
- Sliding speed: 0.74 m/s and 1.143 m/s.
- Normal loading: 200 N, 300N.
- Lubrication: boundary, realized by passing lower part of disc through oil bath, cutting oil ISO 22.
- Contact duration: 60 min, 120 min.
- Measurement equipment:
  - Tribometer TPD-93 for measurement of normal loading, force and coefficient of friction,
  - Talysurf-6 for measurement of parameters of contact body surface topography,
  - Universal tools microscope UIM 21- for measurement of wear of contact surfaces.

Results of tribological investigation contain information about: coefficient of friction, width and depth of wear scar, wear shape of contact surface on block, change of friction coefficient during contact time, topography of block and disc surfaces before and after investigation, wear scar on block and disc, etc.

3. RESULTS OF INVESTIGATION

On the basis of the measurement results for each of three components of cutting resistance, machinability indexes are defined from aspects of main cutting resistance F_1, resistance of penetrating F_2, resistance of feeding F_3, resulting cutting resistance F_R, resultant of penetrating and feeding resistance $F_{R2,3}$, and from the aspect of relation coefficient φ between resultant $F_{R2,3}$ and main cutting resistance F_1. Those indexes are defined with the goal to improve quality of analysis and enable comparison of different difficult to cut materials. Steel Č5741 (Utop extra 1) is chosen as referential material, and machinability indexes are defined as follows:

$$I(F_i) = \frac{F_{iref}}{F_{iisp}} \cdot 100 \qquad (1)$$

Histograms of machinability indexes are formed on the basis of results obtained on that way. Figure 3 shows an example of machinability index according main cutting resistance for group of investigated materials at processing by high-speed tool HSS.E.

Values of tool life are defined for concrete process conditions at adopted criterion of tool wear of h_k=0.2 mm for the tool of HSS.E material and h_k=0.3 mm for the tool of TM material. Those values are defined on the basis of experimental defined curves of wear for the group of investigated materials.

Analysis of results originated from investigation on tribometer and comparison of materials are done from two different aspects: from the aspect of friction coefficient measured on tribometer and from the aspect of wear scar width on block at the end of experiment.

Indexes of materials are formed from the aspect of friction coefficient measured on tribometer and from the aspect of wear scar width measured on block, and comparison of materials are done on the basis of that indexes.

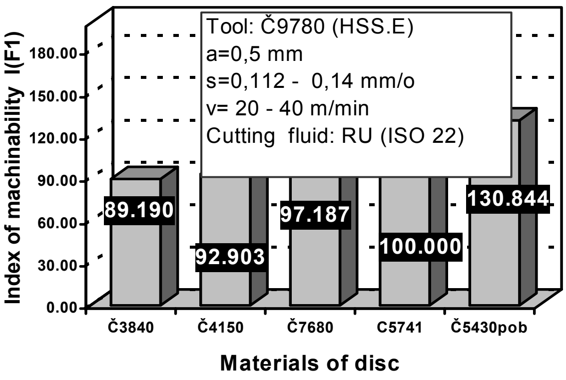

Figure 4: Machineability indexes from aspect of average value of main cutting resistance F_1

Steel Č5741 (Utop extra 1) is choosen as referential material, as well as been chosen at previous processing on lathe. Index of material, from the aspect of friction coefficient obtained on tribometer, is determined as follows:

$$I_{isp} = \frac{\mu_{ref}}{\mu_{isp}} \cdot 100 \qquad (2)$$

Figure 5. shows an example of comparison of investigated materials according this index.

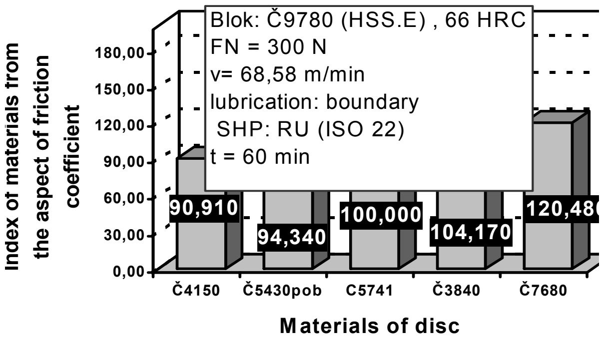

Figure 5: Indexes of materials from the aspect of friction coefficient obtained on tribometer

Indexes of materials are formed from the aspect of wear scar width on the block, obtained on tribometer, and comparison of investigated materials is done from this aspect. It was done on the basis of measured results of average width of wear scar.

Indexes of materials from the aspect of wear scar width on block *b* obtained on tribometer are determined according to:

$$I_{inv} = \frac{b_{ref}}{b_{inv}} \cdot 100 \cdot \qquad (3)$$

Comparative Analysis of Investigation Results at Lathe and on the Tribometer "Block on Disc"

Analyzing results of measurement of cutting resistance at lathe and indexes of machine ability determined according different parameters (F_1, F_2, F_3, F_R, $F_{R2,3}$ and φ), and results of measurement of friction coefficient on tribometer "Block on Disc" and indexes of materials from the aspect of friction coefficient obtained on tribometer, it can be concluded that there is an appropriate coincidence, that is analogy between obtained results. Also, results of measurement of tool wear and wear scar width on block, that is indexes of machine ability determined from the aspect of tool life and indexes of materials from the aspect of wear scar width, point to existing of coincidence between obtained results.

Conditions of investigation on tribometer correspond to conditions of contact between tool clearing face and machining surface, that is sliding speed is approximately equal to cutting speed, and normal loading is approximately equal to radial component of cutting resistance.

By comparison of results of investigation on lathe and on tribometer (Figures 6 and 7), it can be seen that the best comparison between materials is that done by indexes of machine ability, which are defined from the aspect of main cutting resistance F_1 and resulting cutting resistance F_R, and indexes of materials defined from aspect of the friction coefficient measured on tribometer "Block on Disc".

By analyzing results of comparison it can be noticed that there is some coincidence at comparison of materials on the basis of machine ability on lathe from the aspect of main cutting resistance and indexes of materials on the basis of friction coefficient obtained by investigation on tribometer.

This coincidence is related to all investigated materials except for steel Č5430 in improved state, where is certain deviation happen and can be explained by the fact that this steel is of high hardness (40 HRC) and changed structure (improved state). That certainly point to need for investigation of heat treatment influence, that is structure and hardness of materials, to machine ability of materials from the aspect of machining in concrete condition of machining.

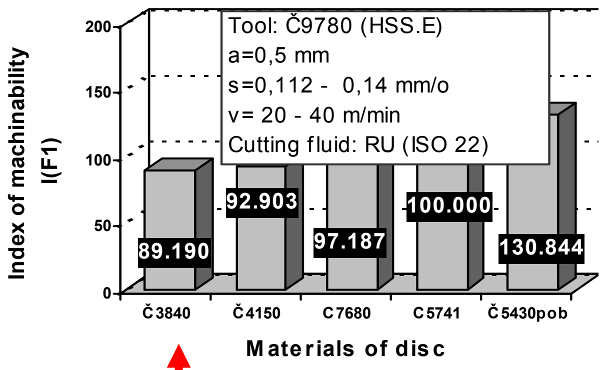

Figure 6: Indexes of machine ability from the aspect of average value of main cutting resistance F_1

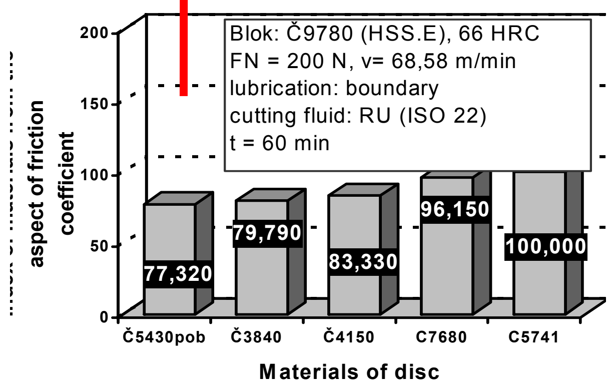

Figure 7: Indexes of materials from the aspect of friction coefficient measured on tribometer

Results of comparison of investigation done on the lathe and on tribometer are shown on Figures 8, 9 and 10.Analyzing results of investigation of tool wear at machining on lathe with tool made of HSS.E and indexes of machine ability of group of investigated materials formed on the basis of that results, it can be shown that there is exceptionally high coincidence with results of investigation on tribometer, where wear scar width on block were measured and indexes of machine ability from the aspect of wear scar width on tribometer were formed.

Relations of materials to machine ability from aspect of tool wear and from aspect of wear scar width on block are almost the same.

Comparison of investigated results regarding to group of investigated materials machined on lathe with hard metal tool and results of tribological investigation shows strong coincidence too (Figures 11,12 and 13)

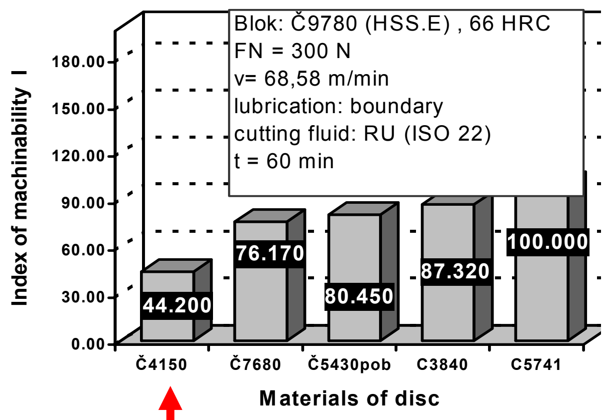

Figure 8: Indexes of materials from the aspect of wear scat width on block made of HSS.E

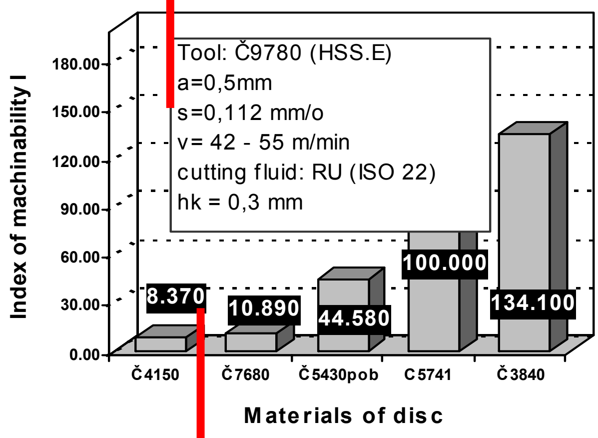

Figure 9: Indexes of machinability from the aspect of durability of tool made of HSS.E

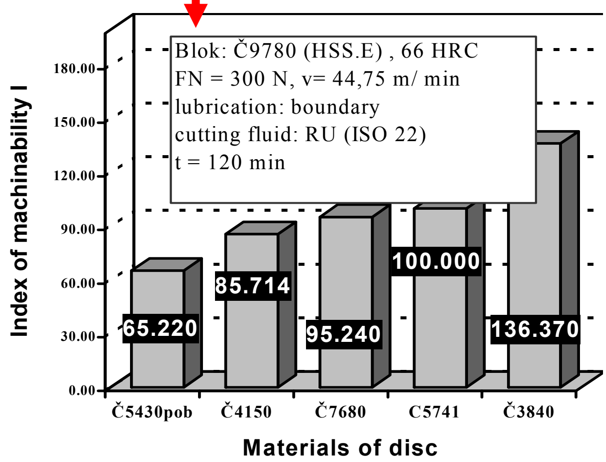

Figure 10: Indexes of materials from the aspect of wear scat width on block made of HSS.E

Investigation of machine ability of group of materials machined on lathe with hard metal tool without coating has been done for two cutting depth (0.5 and 1.0 mm) and experimental results showed that cutting depth has non significant influence to indexes of machine ability.

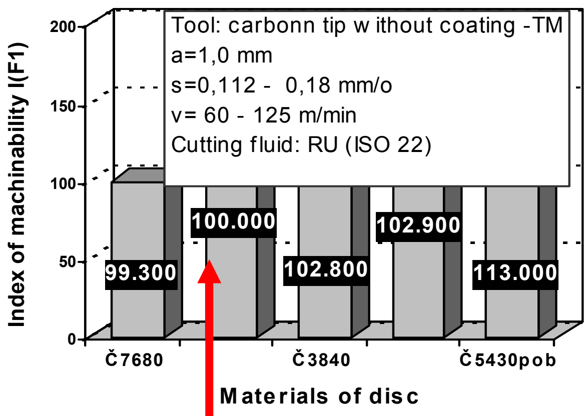

Figure 11: Machine ability indexes from aspect of average value of main cutting resistance F_1

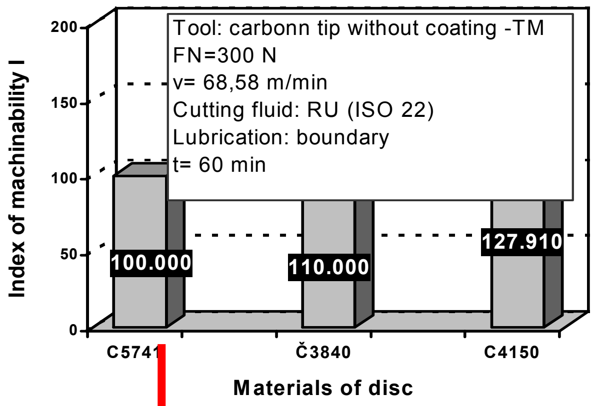

Figure 12: Indexes of materials from the aspect of friction coefficient measured on tribometer

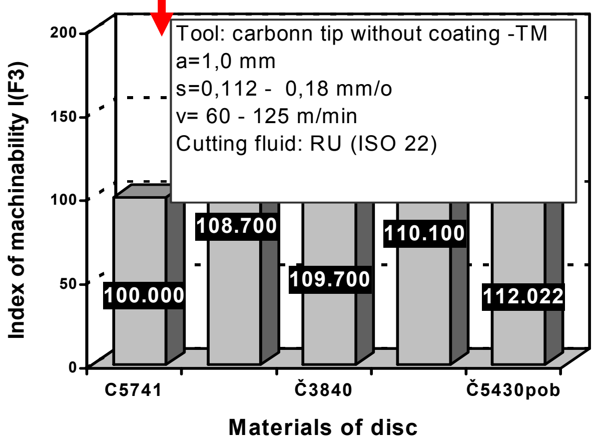

Figure 13: Machine ability indexes from aspect of average value of resistance of feeding F_3

Analysis of results of that investigation shows that Č5741 (UTOP extra 1) and Č7680 (HSS) have had the worst machine ability according to cutting resistance, and Č5430 in improved state and Č3840 (MERILO) have had the best machine ability. At the same time, it is obvious that Č3840 and Č4150 have had very similar values of indexes of machine ability.

By comparison of results of investigation on lathe with tool made of hard metal tool (TM) and results of investigation on tribometer (Figures 10, 11 and 12), it can be seen that the best comparison between materials is that done by indexes of machine ability, which are defined from the aspect of main cutting resistance F_1 and resistance of feeding F_3, and indexes of materials defined from aspect of the friction coefficient measured on tribometer "Block on Disc".

4. CONCLUSION

Proposed model in this paper includes investigation on tribometer 'Block on Disc" where contact is realized by line, which corresponds to conditions of contact between tool insert clearing face and machining surface of work piece. Depending on width and depth of cutting, contact between tool insert rack face and chip can be modeled (simulated) too, by means of line contact between block and disc on tribometer for low cutting depth or feeds, that is small cross-sections of chip (fine machining conditions). For investigation conditions related to rough machining (greater width and depth of cutting, that is greater cross-section of chip) contact is realized by surface , so more realistic conditions of investigation could be obtained by surface contact between block and disc ("Pin on Disc" or "Ring on Disc" tribometer).

In this paper, with relatively simplified model, satisfying results are obtained and imply that investigation of machine ability could be preformed by means of tribological investigation on tribometer "Block on Disc'. Certainly that beginning idea, about changing long-term and costly investigations of different materials machine ability with rapid models investigations on tribometer, is confirmed by presented experimental investigation.

Next step in investigation should point to approaching of conditions of investigations on tribometer and conditions of investigation on tool insert, which means accurate estimate of loadings and speeds on rack and clearing face of tool insert for each concrete case, which is for group of similar investigated materials.
On the basis of verified model for rapid models investigations of materials machine ability on

tribometer, the need and the idea of forming the materials machine ability data base from the aspect of tribological investigation are imposed, which is one of necessary direction of investigation in future.

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