KOKKUVÕTE

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Metallpinnete 3D prinditud mustrite hõõrdumise uuringud, teostatud kuivades libisemistingimustes

Magistritöö

Käesoleva lõputöö eesmärgiks oli erinevate lisandustehnoloogia meetoditega tutvumine ja uurimishüpoteesi kontrollimine (3D metalltrükkimine ehk lisandustehnoloogia võiks olla kasutatud erinevate pinnastruktuuride imiteerimisel triboloogiliste omaduste kontrollimiseks).

Minu panus uurimistöösse oli triboloogia katsetel osalemine, tulemuste analüüs, hoidiku projekteerimine ja pildistamine skaneeriva elektronmikroskoobiga mikroskoobi abil. Antud uurimistöö käigus viisin läbi rea ühesuunalisi libisevaid katseid multifunktsionaalse tribomeetri CETR (nüüd Bruker) UMT-2 abil. Katsete eesmärk oli hõõrdeteguri mõõtmine erinevate pealispinna struktuuride puhul. Katsekehad olid trükitud roostevaba terase pulbrist AISI 316L selektiivse lasersulatuse meetodiga. Katsekehade valmistamiseks kasutati 3D printer Realizer SLM 50.

Realizer SLM 50 – esimene metalldetailide tootmise lauaseade maailmas. See 3D printer on määratud katsekehade loomiseks, mille diameeter ulatub kuni 70 mm ja maksimaalne kõrgus kuni 80 mm.

SLM ehk selektiivne lasersulatus laseb kihiliselt luua kolmemõõtmelisi füüsilisi objekte metallpulbrist laserenergiaga punktpaagutades. Iga mudeli kiht sulandatakse, korrates digitaalse mudeli ristlõikeid. Valmistoodete kvaliteet on niivõrd kõrge, et valmistoodete mehhaanilist töötlust pole peaaegu vaja. Positiivseks efektiks on materjali kokkuhoid – SLM meetod on praktiliselt jääkaineteta tootmine.

Enne ja pärast katset oli tingimata vaja mikrostruktuurset kehade analüüsi teha skaneeriva elektronmikroskoobiga Hitachi TM-1000.

Standardkinnituse kasutamine oli minu katse puhul võimatu. Trükitud katsekehad peavad olema fikseeritud teatud nurga all, et saada struktuurist kvaliteetseid pilte. Seetõttu projekteerisin hoidiku, kus on olemas augud, mis lubavad kinnitada keha paralleelselt lauaga, nurga all 30 ja 45 kraadi. Töö käigus kasutati kaldenurkadena 0 ja 45 kraadi. Hoidik valmistati Tallinna Tehnikaülikooli Materjalitehnika instituudis.

Multifunktsionaalse tribomeetri CETR (nüüd Bruker) UMT-2 abil viidi täide ühesuunalised libisemiskatsed kuivtingimustes (ilma määrdaineta). Katsed viidi läbi pideva koormuse tõstmisega 5-st kuni 103 N (0,5 – 10,5 kg) ja pideva hõõrdeteguri salvestamisega. Katse kestvus oli 10 minutit, et vältida struktuuri täielikku kulumist. Selline meetod lubas kiiresti saada hõõrdeteguri hinnangu laia koormuste intervalliga ühe katse kohta. Ketta pöörlemiskiirus oli 5 mm/s.

Tulemuste analüüsi ajal tehti järeldusi. Esiteks, elementide struktuurisuurused on piiratud SLM printeri võimalustega. Polnud võimalik luua sirgeid fibrille (tulpasid) gekolase tüüpi struktuuri jaoks diameetriga 140 µm ilma moonutusteta. Ilmselt parandamist (tulpade väiksem diameeter) oleks võimalik saavutada SLM parameetrite optimeerimisega. Mis puudutab katset ennast, siis lame katsekeha näitab kõige kõrgemat ja kõige ebastabiilsemat hõõrdeteguri väärtust. See oli tingitud suurte (kuni 1500 µm pikkuste) kulumisosakeste tekkimisega ja tardfaasilise keevitusega. Teiseks, avastati, et geko taldade karvakeste sarnane struktuuritüüp ja kaheksa-vardaline sõrestik näitasid kõige väiksemat ja kõige stabiilsemat hõõrdetegurit (hõõrdetegur = 0.2), mis on 5 korda madalam kui lameda keha puhul. Katkepindadel, mis koosnevad mitmetest väikestest elementidest, on väiksem kontakti pindala ning kulumisfragmentide ilmumise ja kasvamise võimalus on samuti väiksem. Peale selle, vahemik struktuurielementide vahel võib leida kasutust selliste fragmentide (kulumisproduktide) hoidmiseks, mis hiljem võivad välja lennata vältimatu kehade vibratsiooni tõttu. See kinnitab hõõrdumise kontrollimise võimalust pinnasestruktuuride loomisprotsessi kaudu. Ja viimaseks, püramiididel oli kõrge hõõrdetegur ainult katse esimesel etapil, enne otsikute kulumist. Pärast otsikute nüristumist oli nende kehade käitumine pinna süvenditega sarnane ning hõõrdetegur madal. Kui kõrge hõõrdetegur on vajalik pikemaks ajaks, võib kasutada selliste struktuuride tippudes tahket õhukest katet, et suurendada nende tugevust ja vähendada kulumist.

Tulevikus võivad antud töö tulemused aidata määratleda erinevate pinnasestruktuuride kasutamise sihipärasust kahe kokkupuutuva detaili hõõrdeteguri vähendamiseks või suurendamiseks.

SUMMARY

Jevgeni Oštšepkov

Friction studies of metal surfaces with various 3D printed patterns tested in dry sliding conditions

MSc thesis

The aim of the current work was to learn about different methods of additive manufacturing and to prove the hypothesis that "it is possible to control the tribological properties of contacting bodies by creation of their topography by using three-dimensional (3D) metal printing".

Author's contribution into this research was as following: participation in tribological tests, analysis of results, design of holder and making of SEM images before and after tribotesting. I would like to express my gratitude to Yaroslav Holovenko who printed test samples, explained principles of 3D printing and participated in writing of paper for NordTrib 2016 conference (Finland) based on results presented in current work.

3D printed surfaces were produced by Selective Laser Melting (SLM) method from AISI 316L stainless steel powders. Such material of specimens was selected since it was available in laboratory and also due to the fact that contacting stainless steel bodies are prone to severe adhesion and usually are damaging each other quite easily. Stainless steel is perfectly suitable for proving the above stated hypothesis.

3D printer Realizer SLM 50 was applied for production of samples. Realizer SLM 50 is the first tabletop 3D metal printer in the world (available in Department of Materials Engineering of Tallinn University of Technology). This 3D printer is intended to create objects with max diameter of 70 mm and max height of 80 mm.

SLM enables to create layer by layer 3-dimensional physical objects from metal powders by directing the laser into specific points that causes local melting. Object is divided into cross-sections and each cross-section is melted point by point by the laser. The quality of produced parts is so high that additional mechanical finishing operations is often not required. The other positive feature of such process is that there is almost no waists. The unmelted powder could be used during next printing cycle.

Before and after the tribological testing the Hitachi TM-1000 scanning electron microscope was used for microstructural imaging of samples.

It was impossible to use standard fixing methods to study samples under predefined viewing angle. This was required to provide adequate comparison of processes going on during wear to clarify the wear mechanism. Besides it was required to reduce the number of loading cycles into SEM to save equipment (totally 10 types of samples were investigated before and after tribological testing). In order to do it the fixation for two samples staying closely was made. The holder was designed with two slots for each inclination angle (0°, 30°, 45°, 90°). Inclination angle is angle between direction of view and axis of specimen. Inclination angles of 0° and 45° were used throughout the work. The holder was produced in Department of Materials Engineering of Tallinn University of Technology. The permissible displacement of microscope allows to investigate only two samples fixed with the same angle of inclination. There is no need to install any conductive tape between holder and sample. Unidirectional sliding tests were performed with multifunctional tribometer CETR (now Bruker) UMT-2. The aim of such tests was to record the friction coefficient of various 3D printed steel surfaces. Test were performed without addition of any lubricant (dry sliding). The tests were performed with continuously growing normal load from 5 to 103 N (0,5 – 10,5 kg). The friction coefficient (COF) was recorded automatically. The sliding speed was 5 mm/s.

Duration of test was 10 minutes to avoid the complete (especially that of structures made of elements with fine cross sections) wear of printed surface topographies. Such "scanning" method of tribological testing allows getting the overview of friction coefficients of given topographies during one test.

The following conclusions are drawn after analysis of test results. SLM method of steel object 3D printing has limitation of minimal printable element size. It was not possible to create straight fine fibres similar to those occurring on gecko foot with diameter of 140 μm without deformation. It is possible to improve printing capabilities by optimization of printing parameters (adjust laser energy and distance between neighbouring laser attack points).

Regarding the tribological testing, it is possible to add that flat specimen had the highest (COF up to 1.0) and the most unstable (changing abruptly) frictional behaviour. This was associated with formation of solid state welding points and large (up to 1500 μm in length) wear debris. It was found that gecko-type and octet-truss lattice structures had the lowest and the most stable coefficient of friction (close to 0.2) that is up to 5 times lower than that of flat specimen. The surface structure consisting of fine elements that have smaller theoretical contact surface. The possibility for growing of wear debris is reduced. Besides, the space between elements of surface structure could be used for elimination (from wear process) and storage of wear debris that later can escape due to vibration (leading to shortly occurring gap between bodies). Even temporary elimination of debris from wear process can provide their cooling that reduce possibility of adhesive wear.

Samples with pyramids on the friction surface had high friction coefficient only in the beginning of the test before blunting (wear) of pyramid tips. After blunting these samples behaved similarly to samples with dimples and had quite low friction coefficient. In order to provide high friction coefficient of samples with pyramids it is required to coat them with thin coatings (Physical Vapour Deposition, PVD or Chemical Vapour Deposition, CVD) to increase their hardness and to ensure retention of their sharp shape.

The results of current work confirm the hypothesis that it is possible to control the friction coefficient of contacting bodies (even those made of stainless steel).

It is expected that results of current work may facilitate the design of new 3D surface topographies (structures) of parts in contact to control (increase or decrease) their friction coefficient.