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学位論文題目	Mirror Surface Finishing of Miniature V-grooves Using MCF (magnetic compound fluid) Slurry (MCF(磁気混合流体)スラリーを用いた微細 V 溝の鏡面仕上げ)	
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※本研究科以外に所属する場合はその所属を括弧書きすること

論文内容要旨

A novel magnetic compound fluid (MCF) slurry is produced by blending micrometer-size carbonyl iron powders (CIPs), abrasive particles, and α -celluloses whenever necessary into a water-based MF containing nanometre-size magnetite particles with the respective blend ratios. Hence, under a magnetic field, the behaviour of the particles within the MCF slurry can be controlled, and the slurry exhibits a higher magnetic pressure and apparent viscosity and a more stable distribution of particles, while maintaining a fluid-like behavior. In this study, a disc-shaped Nd-Fe-B permanent magnet is affixed on the end face of its holder with an eccentricity. The magnet holder is connected to an electric motor. Once the motor works to rotationally drive the holder, the magnet revolves around the holder axis and thus a rotary magnetic field is generated. In the rotary magnetic field, the magnetic flux density is constant, but the magnetic lines of force constantly revolve around the magnet holder axis. Besides, a MCF slurry carrier made of non-magnetic materials, e.g., aluminum, is located below the magnet with 1 mm, and an adjustable gap of Δ between the carrier and the workpiece is set during the process. When a certain volume of MCF slurry is supplied into the gap Δ , chain-shaped magnetic clusters composed of nm-sized magnetite particles and μm -sized CIPs are formed within the slurry along the magnetic lines of force immediately. The non-magnetic abrasive particles are entrapped into the clusters or distributed between clusters and α -cellulose fibers have interwoven with the clusters. Owing to the magnetic levitation force and the gravity, the abrasive particles move towards the work surface. Once a relative speed is created between the abrasive particles and the work-surface, hence the work-materials are removed by the micro cutting actions of the abrasive particles.

Working life of MCF slurry was studied firstly. In particular, the conventional uncoated-CIPs have low ability against aqueous corrosion, leading to the performance deterioration and working life reduction of water-based

MCF slurry. As a measure against this problem, in the current work a new MCF slurry containing ZrO_2 -coated CIPs instead of the uncoated-CIPs was proposed, and the performance of the new slurry in the polishing of free-oxygen-copper was compared experimentally with that of the conventional one. The work-surface finish polished with the new slurry was in the same level as that with the conventional one when the settling time was less than 24h. As the settling time increased the uncoated-CIPs within the conventional MCF slurry got rusty, leading to a deterioration in the slurry performance. Little rust was observed on ZrO_2 -coated CIPs even the settling time reached several days, indicating the employment of ZrO_2 -coated CIPs prolonged the working-life of the MCF slurry greatly.

To clarify the polishing performance of oxygen-free copper, the effects of process parameters including MCF slurry composition, workpiece oscillation frequency f and clearance Δ between workpiece and MCF carrier on work-surface roughness and material removal were experimentally investigated. As a result, nano-precision surface polish of OFC was successfully attained with MCF slurry. Regardless of the process parameters, the work-surface roughness decreases monotonously with polishing time; although the final roughness depends on the polishing conditions, the roughness of the best work-surface attained in the current work was less than 5 nm Ra. The relationship between the MR and polishing time t is linear under the given conditions. Moreover, the MR s, i.e., the polishing depths, obtained with different parameters; the highest MR s, i.e., the greatest depths, were obtained at $f=30$ Hz, $A_{p-p}=4$ mm, $\Delta=0.6$ mm with a MCF slurry (45 wt.% of CIP, 12 wt.% of abrasive particle, 3 wt.% of α -cellulose, 40 wt.% of MF). In addition, the best surface was obtained in the polished region where the polished area was the deepest.

To find an MCF slurry containing naked CIPs for the nano-precision surface finishing of electroless Ni-P-plated STAVAX steel without particle adhesion or scratching on the work surface, the element of MCF slurry was studied. In order to determine whether the resultant vertical force acts on the CIP and AP either upward or downward, magnetostatic finite element analysis was carried out. Based on the developed model, the magnetostatic simulation was executed using Maxwell software to obtain the magnetic field distribution around the polishing zone at different working gaps for the non-magnetic and magnetic workpiece. The resultant vertical force acting on the naked CIPs was due to the magnetic and gravitational forces, and it significantly increased with increasing CIP diameter. With the magnetic workpiece, the resultant vertical force attracted the CIPs towards the work surface, whereas APs were pushed away from the work surface. Both the CIPs and the APs showed opposite behaviors with the non-magnetic workpiece. The percentage of active APs distributed on the working surface of an MCF slurry increased and the distributions became more even as either the diameter of the CIPs or the working gap increased. On the other hand, the distribution of CIPs was opposite that of APs. The percentage of active APs was beyond 25% with the non-magnetic workpiece, whereas it was less than 25% with the magnetic workpiece. The MCF slurry containing CS CIPs 7 μ m in diameter and APs 1 μ m in diameter should be employed and that the working gap Δ at 1 mm should be set in order to perform mirror surface finishing of magnetic Ni-P-plated STAVAX steel using the naked CIP-based MCF slurry. Under the experimental conditions in this work, the Ni-P-plated surface quality was significantly improved and a mirror surface roughness of $R_a = 4$ nm was successfully achieved without leaving scratches or particle adhesion with an MCF slurry containing CIPs 7 μ m in diameter and APs 1 μ m in diameter. The results demonstrated that use of an MCF slurry containing commercial naked CIPs is a realistic method for nano-precision finishing of magnetic workpieces as long as the CIPs are larger than the APs. This type of MCF slurry has great potential in industrial applications in terms of cost and performance.

To develop an alternative and novel polishing technique for the high-precision surface finishing of miniature V-grooves, the feasibility of finishing V-grooves using the MCF slurry was experimentally determined, and the fundamental finishing characteristics were elucidated. Polishing experiments were performed to clarify the fundamental polishing characteristics, including the variations in the material removal, form accuracy (i.e. form retention rate and symmetry error), and surface roughness at different polishing areas during polishing. The fundamental characteristics were determined by investigating the distribution of the abrasive particles in the polishing zone, relative velocity of the abrasive particles compared to the V-groove, and impact angle of the abrasive particles against the V-groove side surface. The effect of the MCF carrier rotation speed n_c on the characteristics was elucidated, and an appropriate value for n_c was proposed from the viewpoint of the balance between the form accuracy and surface quality Ra. The impact angle θ was determined based on the MCF carrier rotational speed and workpiece vibration speed, and varied periodically with time; the form accuracy was greatly affected by the effective impact angle θ_m , which was the value of θ at the moment when the relative velocity peaked. The V-groove form accuracy, i.e. the form retention rate η and symmetry error ε , deteriorated during polishing, and the final form accuracy differed with the location in the polishing zone, which was attributed to the different θ_m values at different locations. The form accuracy was worse at a location where the absolute value of θ_m was larger. Nevertheless, the form retention rate η and symmetry error ε at the location where the form accuracy was the lowest were more than 99.47% and less than 0.17, respectively, which satisfied the requirements for the injection mould of a sunlight concentration Fresnel lens. At the majority of locations, the surface quality Ra values at the upper positions of the V-grooves were better than those at the lower ones. At the locations where the motion of the abrasive particles was from the right/left side to the left/right side of the grooves, the surface quality Ra values at the right/left side were better than those at the left/right side. The differences in the surface quality Ra values at the different positions were different at different locations, and the difference was larger at a location where θ_m was larger. The final surface roughness values after 150 min of polishing were in the range of 15–50 nm Ra at all the discussed locations/positions, indicating that a mirror-like surface could be successfully achieved for a miniature V-groove. Increasing the MCF carrier rotational speed n_c led to an increase in θ_m and hence deteriorated the form accuracy, but improved the surface quality Ra. Taking into account the balance between the form accuracy and the surface quality Ra, n_c should be set at 10 rpm under the experimental conditions in the current work. In the finishing of the circular grooves, both the form retention rate and surface roughness decreases with the increasing of workpiece rotational speed. In addition, the polished surface roughness on top and bottom of the grooves can keep consistent when the workpiece is Ni-P plated surface.