別紙４（課程博士）

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Abstract

論文内容の要旨　（博士）

Title of Thesis 博士学位論文名	Reduction in Friction in Ironing of Aluminium Alloy and Stainless Steel Drawn Cups （アルミニウム合金とステンレス鋼深絞り容器のしごき加工における摩擦の低減）

(Approx. 800 words)

（要旨　1,200 字程度）

In Chapter 1, the general introduction for overall contents of this thesis is presented. Because of growing awareness of environmental protection, there is a requirement to reduce CO_2 emission from automobiles. The reduction in weight of automobiles and the technologies for electric and hybrid vehicles play an important role in reducing greenhouse gas emissions. The key component for electric and hybrid vehicles is batteries. Metal cups used as battery cases are produced by multi-stage stamping operations including deep drawing and ironing of stainless steel and aluminum alloy cup. Since ironing involves a high contact pressure and high speed, friction plays an important role in the success of the ironing process. Reduction in friction with low friction tool materials, lubrication and coating is presented.

In Chapter 2, a TiCN-based cermet die having low friction was applied to improve the limit in ironing of stainless steel and aluminum alloy drawn cups. In this cermet die, an additional surface coating is not required because it was made of hard TiCN having low friction without WC and Co. For all the stainless steel and aluminum alloy drawn cups, the cermet die exhibited the largest ironing limit for single ironing due to the low friction. For repeated ironing using the cermet die, the seizure was prevented up to 100 times.

In Chapter 3, the TiCN-based cermet dies having fine lubricant pockets made by lapping shot-peened surfaces were utilized to reduce friction in ironing of stainless steel and aluminium alloy drawn cups. The shape of the lubricant pockets was controlled to improve the ironing limit. The ironing limit was improved for the die having an appropriate surface shape of fine lubricant pockets. Friction was reduced by liquid lubricant squeezed out from the pockets during ironing, and the ironing load became smaller. The mechanism of the superior seizure resistance of the die having an appropriate surface shape was examined from the remaining amount of lubricant in ironed cups.

In Chapter 4, the conditions of the ironing process and lubrication for attaining low friction in ironing of stainless steel cups using the cermet die having fine lubricant pockets were investigated. The thickness of the remaining lubricant on the sidewall of the ironed cup was measured by mixing a fluorescence oil in the lubricant. When the amount of lubricant was sufficient and the ironing speed was high, the ironing load was lower than that of a die having a polished surface. In repeated ironing, the surface roughness of the ironed cup for the die having the lubricant pockets was almost constant.

In Chapter 5, the TiCN-based cermet die having fine lubricant pockets and roughening of drawn cup surface were utilised to reduce friction in ironing of stainless steel drawn cups. Sanding with emery papers, deep drawing with large clearance, and deep drawing including redrawing with a small die radius were employed to roughen the drawn cup surface. The effects of the sanding direction and the surface roughness of the cups having the roughened surface on the ironing limit were investigated. During ironing, the lubricant was trapped with the cups sanded in the circumferential direction and the ironing limit was higher than with the cup sanded in the axial direction. Friction in ironing was lowered by roughening of cup surface because the lubrication was enhanced.

In Chapter 6, the lubricants containing the fine particles were utilised to improve seizure resistance in ironing of aluminium alloy drawn cups. The effects of types and size of particles on the improvement of seizure resistance were investigated. The mixing lubricant with silica (SiO_2) particles having a size of 0.01 μm improves the seizure resistance. The good dispersion and suspension of the fine SiO_2 particles in the lubricant enhanced lubrication. The effect of different mixing quantities of fine SiO_2 particles in lubricants on the seizure resistance was examined. For a low viscosity lubricant, the fine SiO_2 particles had a little effect on increasing the ironing limit. The ironing limit was improved only with a large

quantity of SiO_2. The seizure resistance was effectively improved by applying the high viscosity lubricant with the fine SiO_2 particles.

In Chapter 7, titanium nitride (TiN) and vanadium nitride (VN) coatings were deposited on high speed steel substrates by direct current magnetron sputtering to improve seizure resistance in ironing of aluminium alloy cups. Coating parameters were optimised to obtain phase compositions of TiN and VN. The coatings were characterised for phase composition using X-ray diffraction (XRD), hardness using nano-indentation and load-to-failure between the coating and substrate using scratch testing. Ring-on-disc testing was carried out to evaluate the tribological properties between aluminium alloy rings sliding against high speed steel discs with a lubricant. Finally, the coating which mainly had the superior tribological properties was further evaluated in ironing of an aluminium cup.

In Chapter 8, concluding remarks are presented and future perspectives for improving the seizure resistance are given.