論 文 の 要 旨

題 目 Wear mechanism of coated carbide tools in the machining of ductile cast iron

(ダクタイル鋳鉄の機械加工における被覆工具の摩耗メカニズム)

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In this study different aspects related with the wear on coated carbide tools when turning and face milling ductile cast iron were studied. A total of five different workpieces were tested; two different ferritic ductile cast iron, one pearlitic-ferritic ductile cast iron and two pearlitic ductile cast iron. The coated tools used were TiN, TiCN and TiAlN coated carbide tools. These work can broadly be divided in three different sections:

In the first section TiN and TiAlN coated carbide tools were used in turning of ferritic ductile cast iron (named F400 and F440) and pearlitic ductile cast iron (named P520 and P675). Plain carbon steel (AISI 1045) was used as baseline workpiece for comparing its machinability with the machinability of ductile cast iron. Experimental measurements include: evaluation of mechanical properties of workpieces and its microstructure, measurement of cutting forces, measurement of cutting temperature and measurement of flank wear.

The microstructure of ductile cast iron contains nodules of graphite. The spheroidal shape of graphite gives to ductile cast iron superior ductility and strength than gray cast iron with graphite in the form of flakes. The microstructure of ferritic ductile cast iron contained around 4% of lamellar pearlite. On the other hand, the microstructure of pearlitic ductile cast iron consisted in pearlite with only around 8% of ferrite. Ferritic ductile cast irons has higher ductility than pearlitic ductile cast iron; but tensile strength of ferritic ductile cast iron is lower the tensile strength of pearlitic ductile cast iron.

The largest cutting forces were measured when turning pearlitic ductile cast iron. Cutting forces when tuning pearlitic ductile cast iron were similar to those measured when turning plain carbon steel. The lowest cutting forces were measured when turning ferritic ductile cast iron. The fluctuation of friction coefficient on the rake face was analyzed in order to evaluate the cutting speed at which BUE occurs. The largest fluctuation of friction coefficient occurred at low cutting speed. In the case of the coated carbide tools, as the cutting speed increased, the fluctuation of friction coefficient decreased. These results were confirmed by the images of taken at the cutting speed of 50 m/min and 150 m/min. Furthermore, the measurements of BUE height confirmed that on TiAlN coated carbide tool the BUE was the lowest. The height of BUE was measured at low cutting speed. The results showed that the amount of BUE depends on the cutting speed, type of ductile cast iron and type of tool. The height of BUE decreases as the cutting speed increases.

The measured cutting temperature was the highest in the turning of pearlitic ductile cast iron. The cutting temperature increased with the cutting speed; a linear relationship between cutting temperature and cutting speed was observed when plotting in log-log scale. The difference between cutting temperature when turning ferritic ductile cast iron and pearlitic ductile cast iron was around 100ºC. The high temperature caused in turning pearlitic ductile cast iron had a detrimental effect in the tool wear.

Flank wear was the highest in the turning of pearlitic ductile cast iron. TiAlN coated carbide tool outperformed TiN coated carbide tool regarding flank wear due to the better stability of TiAlN coating at high temperature. In general, flank wear on coated carbide tools was larger in turning of ductile cast iron than in turning of plain carbon steel.

It was found that, ductile cast iron has lower machinability than plain carbon steel. In order to explain the relatively low machinability of ductile cast iron, a tool wear mechanism was proposed. This mechanism is based in the composite nature of ductile cast iron. Ductile cast iron has a hard matrix in which soft graphite is disperse. It is thought that the continuous passes of the tool from soft graphite to hard matrix causes a phenomenon similar to interrupted cutting provoking an increase in wear rate by chipping and adhesive wear. A particular characteristic in the behavior of the flank wear progress of coated tools plotted versus the cutting length in logarithmic scale was observed. This characteristic corresponds to the change in wear rate when the relationship between flank wear and cutting distance was plotted in log-log scale. This change in wear rate was associated with the loss of coating on the cutting edge. The wearing out of coating layer was observed in SEM images and corroborated by the element distribution images.

In the second section, TiN and TiCN coated carbide tool were used in face milling of ductile cast iron. The cutting conditions used in face milling were similar to those used in turning. The principal difference between turning and face milling, regarding tool wear, was found in the face milling of ferritic ductile cast iron. When face milling ferritic ductile cast iron, notching wear was the tool life limiting factor, while in turning of ferritic ductile cast iron it was flank wear. The tool life was six times longer in turning than in face milling of ferritic ductile cast iron. The reasons of notching wear on TiN coated carbide tool when face milling ferritic ductile cast iron are oxidation wear, work hardening, burr formation and adhesive wear. It is thought that adhesive wear is the principal cause of notch wear due to the high tendency of ferrite to adhere on the tool. Furthermore, as the tool passes near the end burr, part of the high work hardened burr may stuck on the tool cutting edge, causing chipping when the tool reengage in the workpiece. The results demonstrated that TiCN coated carbide tool did not show notching wear when face milling ferritic ductile cast iron. Therefore, an appropriate choice of the coating can prevent notching wear.

In the third section, a pearlitic-ferritic ductile cast iron was turned with a TiN coated carbide tool. The measured mechanical properties of pearlitic-ferritic are intermediate to those of ferritic ductile cast iron and pearlitic ductile cast iron. However, pearlitic-ferritic ductile cast iron has a tensile strength of 500 MPa which is close to the tensile strength of pearlitic ductile cast iron P520. However, the machinability and ductility of the pearlitic-ferritic ductile cast iron tested were superior to those of pearlitic ductile cast iron. Therefore, a ductile cast iron with similar tensile strength to pearlitic ductile cast iron but with improved machinability and ductility can be made by controlling the amount of ferrite in the microstructure.