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HOT MACHINING OF HIGH MANGANESE STEEL: A REVIEW

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ABSTRACT
High manganese steels are called as difficult-to-cut materials because of its mechanical properties such as high strength, toughness, wear resistance and low thermal conductivity. Moreover work-hardening property of these materials adversely affects the machinability of high manganese steels. Therefore new approach has been developed to machine these types of materials and the machining method is named as "hot machining". The workpiece material is preheated or heated during machining operation in hot machining method and it was reported that many advantages have been observed like longer tool life, better surface finish and cost-effective production. In this study, firstly high manganese steels are briefly introduced and the application of hot machining method is extensively examined in the case of high manganese steels. The effects of machining parameters (cutting speed, feed rate, depth of cut) on tool wear, surface roughness and cutting forces are examined and comparisons of hot machining and conventional machining are carried out. The review study aims of providing scientific data for hot machining of high manganese steels.
Keywords: High manganese steel, machining, hot machining, tool wear, surface finish

1. INTRODUCTION
High manganese steels are, also known as Hadfield steel or austenitic stainless steels invented by R.A. Hadfield in 1882. His invention provided new material which was stronger, harder and tougher than steel [1-4]. High manganese steels mainly contain around 0.7-1.4% carbon and 6-25% manganese with small amounts of other elements such as silicon, phosphorus, chromium, molybdenum, nickel, nitrogen, vanadium, bismuth, titanium, zirconium, calcium, sulfur, selenium, lead and tin. The combination of these elements, particularly carbon-manganese percentage provides unique properties to high manganese steels like high toughness, high wear resistance, low thermal conductivity, non-magnetic and work-hardening. These properties made the material wide industrial application such as rock crushers, grinding mills, dredge buckets, power shovel buckets and teeth pumps for gravel and rocks for different industries like earthmoving, mining, quarrying, oil well drilling, steel making, transport, nuclear fusion reactors, etc. It is also used in sprockets, pinions, gears, wheels, conveyor chains, wear plates and shoes etc. due to resist metal-to-metal wear [5-6].

The machinability of high manganese steels is difficult due to its properties, particularly work-hardening property. During machining process of this material, plastic deformation occurs in the workpiece material ahead of the shear zone. Dislocation motion is related to its work-hardening property causes additional compression after shear. A sharp cutting tool acts as concentrated source of the dislocation movements and develops a catastrophic shear front in a narrow region of shear zone. The catastrophic shear that releases the applied load is related to the interference of the dislocation movements caused by the work-hardening property of the machined material or the increases in compressive strains ahead of the cutting tool tip. Therefore rapid tool wear occurs as well as built-up edge on cutting tool tip. Moreover, the low thermal conductivity causes difficulties during the machining operation [7]. As a result, high manganese steels present various difficulties that are why the material is called difficult-to-machine.

It is clearly noticed from literature survey that the low machinability of high manganese steels is widely recognized. Therefore, it is important to overcome this problem by using different approaches or methods in machining process for these types of materials. One of these methods is called “hot machining”.

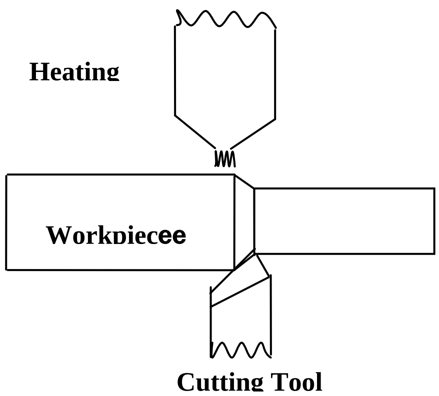

Figure 1. Schematic hot machining application

The workpiece material is heated prior to or during machining operation, thus the locally softened material becomes easy-to-cut (Fig 1). Wide application of hot machining for different materials has been examined like stainless steels, tool steel, composites, nickel-based alloys, Inconel, titanium, ceramics, as well as high manganese steels [8]. Various heating methods have been developed for hot machining such as electric current, flame, induction heating, arc heating, plasma arc, high frequency, laser etc. Every heating method has some advantages but later studies based on laser assistance hot machining. The advantages of hot machining process comparing to conventional machining are lower machining cost (reduction around 30-80%), longer tool life (2-5 times), and better surface finish quality.

In the present paper, the machinability of high manganese steels using hot machining method has been reviewed in detail. The influences of machining parameters (cutting speed, feed rate, depth of cut) on tool wear, surface roughness and cutting forces were examined and comparison of hot machining and conventional machining were carried out. The review study aimed of providing scientific data for hot machining of high manganese steels.

2. HOT MACHINING OF HIGH MANGENESE STEELS

One of the main reasons why hot machining is vital solution in the machining of high manganese steel is the effect of hardness related to temperature. This relation has been reported by Kopac [9] and he provide important information that how the temperature reduces hardness of the material after 500 °C (Fig 2). Therefore the heated material would lose its hardness and related properties during hot machining process.

The first study on hot machining of high manganese steel was reported by Armstrong et. al. [10]. They noticed that the material was metastable austenite at room temperature thus it was soft and ductile. However the austenite transformed to stable martensite during machining which made the material hard and brittle. Therefore it was impractical to machine high manganese steel at room temperature. They machined this material at higher temperature and it was observed that martensite transformation did not occur. They concluded that hot machining improved machinability property of the material.

Pal and Basu carried out hot machining of high manganese steel in shaping operation [11]. Oxy-acetylene torch as heating method was used just ahead of the carbide cutting tool. It was noticed that tool life increased with application of higher temperature (up to 650°C). Tool lifes were 1 min at room temperature, 5-6 mins at 400°C, 7-8 mins at 500 °C and 10 mins at 650°C.

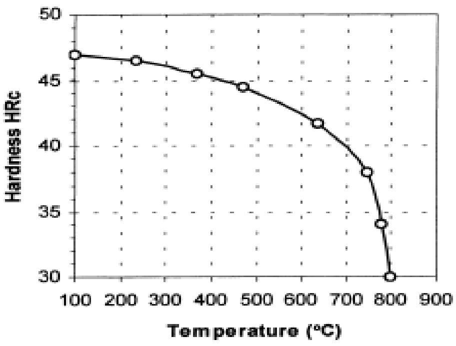

Figure 2. The change of hardness vs. temperature

Chamber used HoMach Machine Tool especially built-up for hot machining operation in his study [12]. He reported that it was possible to use higher cutting speeds in hot machining of high manganese steel comparing to conventional machining processes. The material removal rate improved, increased around 300% by hot machining of this material.

Moore carried out some experimental studies using specially designed machine tool using plasma heating method for hot machining operation, called PERA CUTFAST [13]. He reported that the material removal rate 12 times higher in hot machining of high manganese steel comparing to conventional machining.

Uehara et. al. used electric current heating method for hot machining of high manganese steel with different cutting tool materials (carbides - K10, P10, P20 – and cermets) [14]. They reported that coated carbide cutting tools provided better results. They concluded that hot machining could be a favourable method for machining of low machinability or difficult-to-cut materials.

Maekawa et. al. used plasma arc heating method in hot machining of high manganese steel [15]. They observed that cutting forces reduced, tool wear decreased at low cutting speeds and there was no chatter in machine tool. They also reported a better surface finish with application of hot machining method [16]. Moreover these two studies provided simulation analysis of hot machining of high manganese steel [15,17].

Roy et. al. hot drilled high manganese steel and reported that hot drilling was better comparing to conventional drilling operation even for thick workpiece [18]. Moreover, carbide precipitation at the grain boundaries during the hot drilling process was local at heated spots.

Çakır and Altan examined cutting tool geometry on tool life and surface finish and reported that higher tool life and better surface finish quality could be obtained using hot machining comparing to conventional machining [19]. It was noticed that negative rake tool angle could be better in hot machining of high manganese steel.

Ozler et. al. studied tool life in hot machining of high manganese steel and mentioned that hot machining provided longer tool life in comparison to conventional machining [20]. Optimization of hot machining for high manganese steel was carried out by Tosun and Ozler [21,22].

The literature review showed that the machinability of high manganese steel with hot machining method would provide better machining outputs such as longer tool life, lower surface roughness and higher material removal rates.

3. CONCLUSION

The machining behavior of high manganese steel has been studied and their findings have been reviewed. The most important factor in machining of high mangansese steel seems to be work-hardening property as well as hardness and low thermal conductivity. This property demonstrates to cause high localized stresses and temperatures in the contact area of chip and tool. Therefore rapid tool wear and poor surface finish quality occur. Thus low cutting speeds are recommended in conventional machining of high manganese steel. This would result low material removal and high machining cost. Hot machining seems to be option to overcome these problems. Different heating methods is available for hot machining of high manganese steels, the ideal heating method is the one just ahead of the cutting tool, locally heating the material's cutting zone. Various cutting tool materials have been applied, but carbides were generally recomended for hot machining of high manganese steels. Various experimental studies have reported that higher tool life, lower cutting forces and better sruface finish quality could be obtained by using hot machining method for high manganese steel comparing to conventional machining operation. This would positively influence material removal rate and machining costs.

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