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A study on grinding chips formed during surface conditioning of continuously cast stainless steel slabs

Chips of various morphologies formed during surface grinding of cast AISI 409 stainless steel slabs have been examined in light microscope and SEM. Dynamic nucleation of fresh grains occur in the work hardened layer of chips of various morphologies, but growth of these grains on the chip surface is highly non-uniform. Iron rich oxide nodules also grow on the chip surface.

Introduction

Stainless steels do not generally machine as well as mild steels. Machining problems originate from their higher strength, propensity to work hardening and much reduced thermal diffusivity[1]. Interaction between the alumina wheel and the work piece and formation of micro cracks and micro voids influence the ground surface characteristics of stainless steels[2]. The morphological characteristics of the machining chips correlate well with the internal dislocated structure of the chips as observed in TEM[3]. The present limited study was undertaken to investigate the morphology and microstructures of chips generated during grinding of 409 stainless steel slabs in an alloy steels plant. Since the chips examined in this investigation were generated during industrial processing, no attempt has been made to correlate the chip characteristics with grinding parameters like speed, feed and depth of cut.

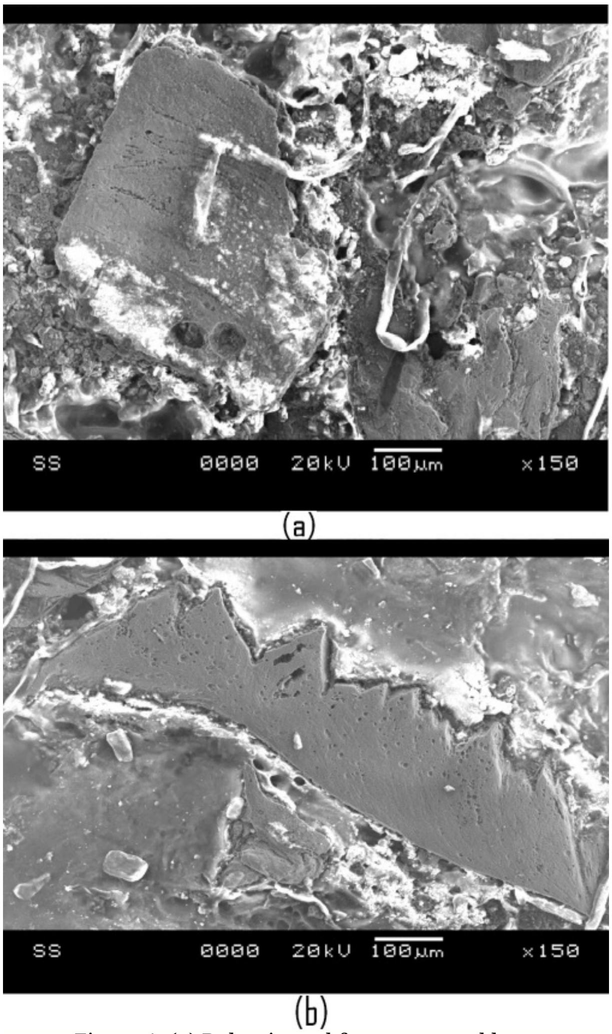


Figure 1: (a) Delaminated fragments and long ribbons, (b) Saw tooth type chip.

Experimental procedure

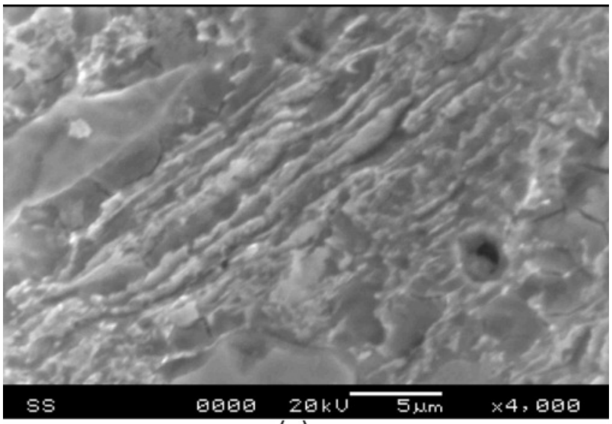
Surfaces of continuously cast 409 grade stainless steel slabs of nominal composition C 0.08 max, Cr 10.5 – 11.75, Mn 1.0 max, Ni 0.5 max, P 0.045 max, Si 1.0 max, S 0.045 max, balance Fe are usually conditioned by grinding. Chips formed during such grinding operation were collected for this study. The chips were mounted in thermo setting resin (Bakelite), lightly polished and then etched in aqua regia for metallographic examination. The chips were also examined in SEM; EDS analysis was also carried out.

Results and discussion

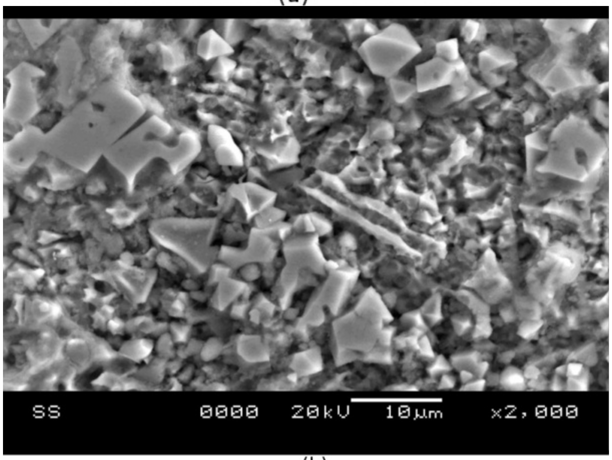
On examination in SEM at low magnification, chips of various morphologies such as delaminated fragments, long ribbons and saw tooth type chips could be observed. (Fig 1 a,b) The ribbons are generally formed due to ploughing action of the grits of the alumina grinding wheel. In fact distinct ploughing marks could be detected in some chips. (Fig 2a) The delaminated chips are normally formed by nucleation and propagation of subsurface cracks under the influence of grinding stress. Fig 2b shows that a part of the surface layer has already been delaminated while the delamination process is in progress in rest of the surface. Ploughing marks are also visible. Formation of saw tooth chips indicate alternate sticking and slipping[4].

The microstructures of the polished and etched chips were examined in light microscope. Fig 3 (SEM) shows fully recrystallised grains and non-recrystallised areas in a delaminated chip. A similar phenomenon was observed in a saw tooth chip as well. (Fig 4) As expected, the chips are heavily cracked. (Fig 5) Dynamic recrystallisation of grains in stainless steels following severe hot plastic deformation during grinding has been reported earlier by several investigators [5-6] However, the non-uniform growth of grains even in a tiny chip suggests that the adiabatic heat transfer condition[7]. prevailing during the grinding operation results in the development of a non-uniform temperature profile even in a tiny chip, presumably due to the low thermal conductivity of stainless steels.

Growth of oxide nodules could be clearly observed on some of the chips. (Fig 6) The EDS analysis of an oxide nodule along with the spectrum is shown in Fig 7. The proportion of iron in the oxide is much



(a)



(b)

Figure 2: (a) Ploughing marks on chips, (b) A chip showing progress of delamination

greater than that of chromium. It obviously indicates large scale diffusion of iron in the oxide nodule. Other chips were also found to be coated with a layer of iron oxide, although growth of nodules on their surface was less conspicuous. (Fig 8) These observations clearly indicate that the protective chromium oxide layer is ruptured during grinding. Apart from mechanical deformation very high temperature developed at the tool chip

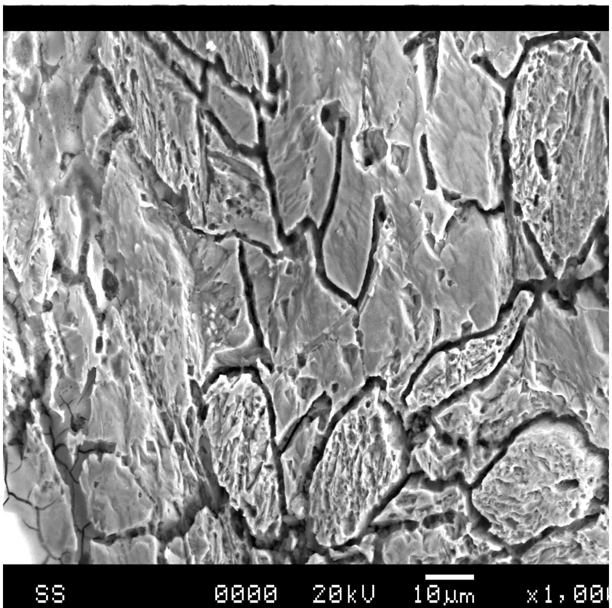


Figure 3: SEM view of a deep etched chip: Fully recrystallised grains and non-recrystallised areas

interface may also be responsible for breakdown of the protective chromium oxide layer, which in turn permits iron diffusion along grain/phase boundaries [8].

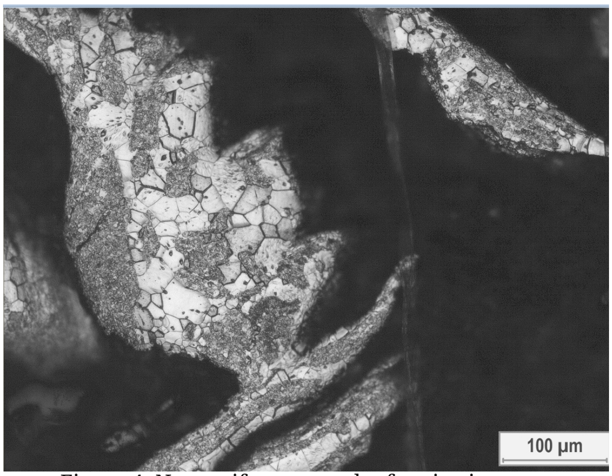


Figure 4: Non-uniform growth of grains in a saw tooth chip

Conclusions

1. Chips of various morphologies such as ribbons, delaminated fragments and saw tooth type are formed during grinding of 409 stainless steel slabs.

2. During grinding, dynamic nucleation of fresh grains occur in the work hardened surface layer of chips. Some grains also undergo appreciable growth. Such non-uniform growth of grains indicates non-uniformity of temperature profile even in tiny chips.

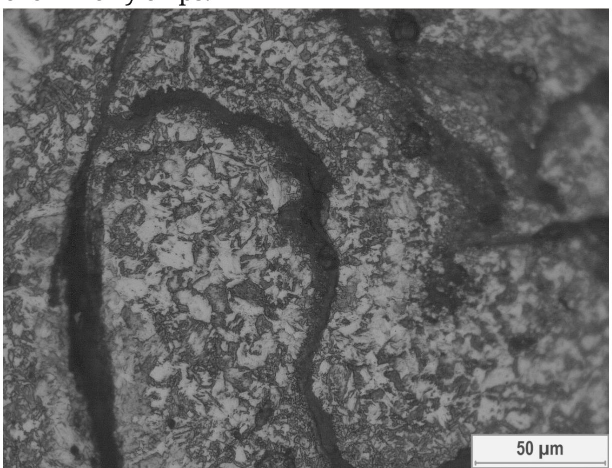


Figure 5: Progress of cracks through chips

3. The protective chromium oxide layer is ruptured during grinding. This permits growth of iron rich oxide nodules on the chips due to oxidation of the base iron.

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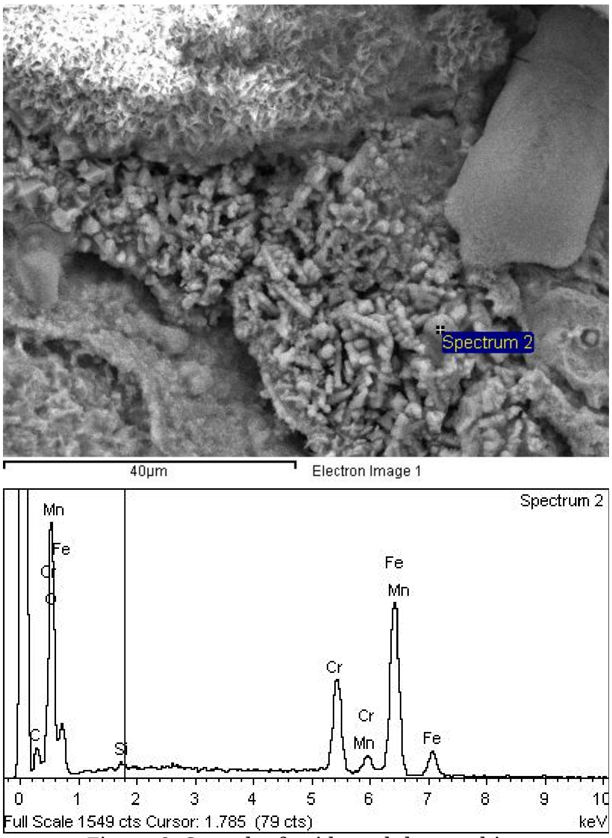
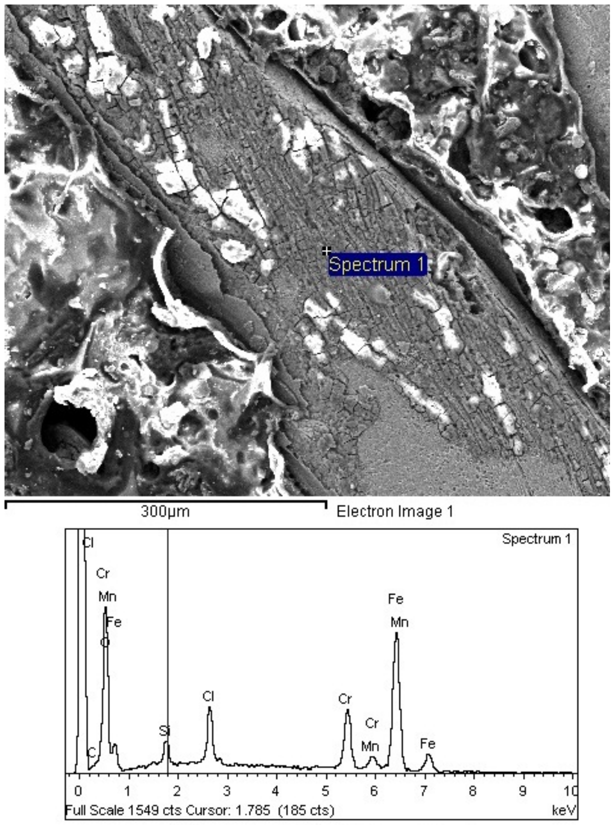
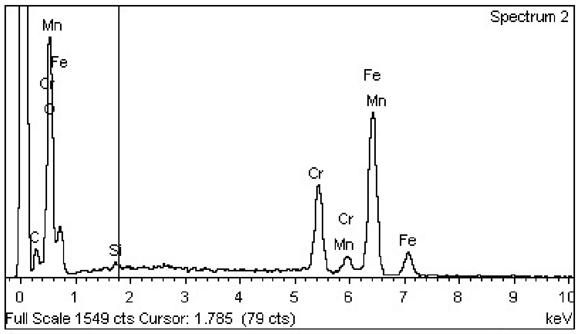


Figure 6: Growth of oxide nodules on chips



Element	Weight%	Atomic%
C K	0.00	0.00
O K	33.59	61.53
Si K	2.61	2.72
Cl K	5.94	4.91
Cr K	11.92	6.72
Mn K	1.54	0.82
Fe K	44.40	23.30
Totals	100.00	

Figure 7: EDS analysis of an oxide nodule. The carbon signal is obviously picked up from the Bakelite mount and may therefore be neglected



Element	Weight%	Atomic%
C K	9.90	20.24
O K	36.03	55.33
Si K	0.48	0.42
Cr K	13.16	6.22
Mn K	1.03	0.46
Fe K	39.40	17.33
Totals	100.00	

Figure 8: EDS analysis of the surface of a delaminated fragment

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