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HOT SHORTNESS IN STEELS AND A NOVEL APRROACH

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Hot shortness in steel is a result of tramp element accumulation in recycled steels, mainly Copper (Cu). Cu refinement in conventional steel production method is not achievable. Studies are concentrated on slag chemistry, magnetic separation and chlorination of steel scrap. We report a novel and simple approach in elimination of surface Cu segregation from steel. Cu is found to be accumulating on the steel surface in oxidation process. Oxidation of thin steel slabs concentrates Cu on the steel surface in short time. Machining of the steel surface eliminates Cu segregation and macro surface cracks. Results showed that satisfying mechanical properties can be obtained from machined steel samples.

Keyword: steel, copper, segregation, X-ray analysis, mechanical properties.

INTRODUCTION

Steel is the most produced metallic material worldwide with 1808 million tonnes annual production in 2018[1]. Electric arc furnace (EAF) share in the production of steel is the 28,8 % in 2018 [1].

EAF route uses scrap steel in general for recycling of steel. Recycled steel has lower carbon footprint in production and preserving depleting raw material in the world [2]. Although it is environmentally friendly to recycle steel it has unique problems [3].

Hot shortness is one of the major problems in recycled steels due to presence of tramp elements [4-13]. Tramp elements are accumulated elements in steel production with every recycling step due to thermodynamic restrictions [3]. Tramp elements have higher oxidation Gibbs Free Energy than Fe thus remain in steel bath during slagging operations [3]. The major tramp element in steel recycling is Cu with highest impact on hot working of steel and amount in scraps [14]. It is forecasted that steel industry will be dealing with higher amount of tramp Cu in steel scrap than tolerable amount by the year 2050 [14].

The effect of Cu to steel is known as hot shortness [4]. Hot shortness is surface cracks on the steel due to segregated and liquefied Cu on the surface [6]. Elements of Ni and Si alloying in to the steel is found to be reducing the hot shortness vulnerability of the steel [9], [15]. Oxidation of Cu containing steel causes Cu segregation on the oxide scale-metal surface [16], [17]. Segregated Cu on the steel surface causes intergranular cracks during the hot working of steel [4,6,8,18].

This paper investigates mechanical properties of 2,58 % Cu containing steel after machining of surface of hot shortness failure.

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Table 1 **Chemical composition of steel/ wt. %**

C	Mn	Si	Cr	Ni	Cu
0,44	2,83	0,18	0,11	0,09	2,58

EXPERIMENTAL

Steel slab was smelted in induction furnace then casted in resin mould. Casted slab was size of 20 x 200 x 2 500 mm. Chemical composition of steel was characterized with Optic Emission Spectroscopy technique and results were given in Table 1. Casted steel slab hot rolled at 1 200 °C after annealing for 1 hour. 50 % reduction in area was obtained with hot rolling simulation machine. Surface characterization of hot rolled slab was carried out with Scanning electron microscopy (SEM) and optic microscopy. Microstructure samples were etched with 3 g $FeCl_3$/ 10 ml H_2O_2 / 100 ml distilled water. Tensile test specimen was prepared via machining of hot rolled slab. Tensile test specimen was machined in cylindrical form with diameter of 8 mm.

RESULTS AND DISCUSSION

Slab surface is investigated and optic microscopy view is given in Figure 1. Surface Cu segregation and hot shortness is seen on the steel surface. Etchant reveals Cu segregation in orange copper colour. Intergranular crack and Cu segregation along with the crack length can be seen.

SEM observation is carried out to hot rolled slab surface. Energy dispersive spectroscopy (EDS) mapping is used to determine Cu distribution and verifying Cu segregation on the optic microscopy image. SEM image is given in Figure 2 while EDS mapping is given in Figure 3. Bright fields in backscattered electron image are found to be Cu segregation in EDS mapping. Green dots in EDS mapping shows Cu signals collected from sample. Figure 3 shows that Cu segregation extensively accumulated on surface and crack edge.

Figure 1 Cu segregation and crack on steel surface

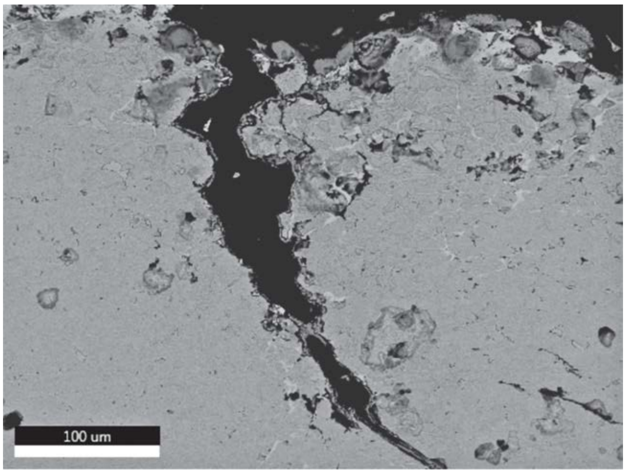

Figure 2 SEM image of surface crack on the steel surface

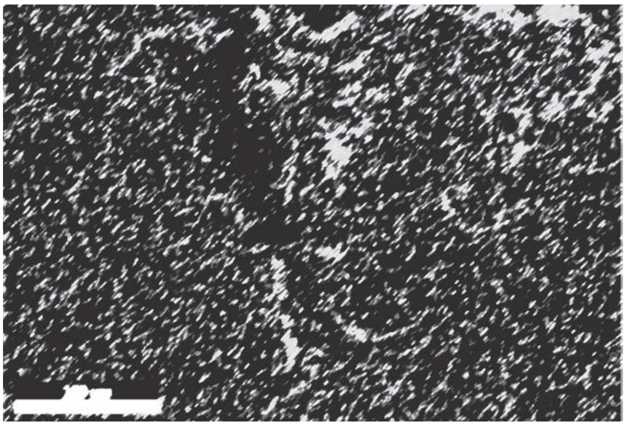

Figure 3 EDS mapping of Cu

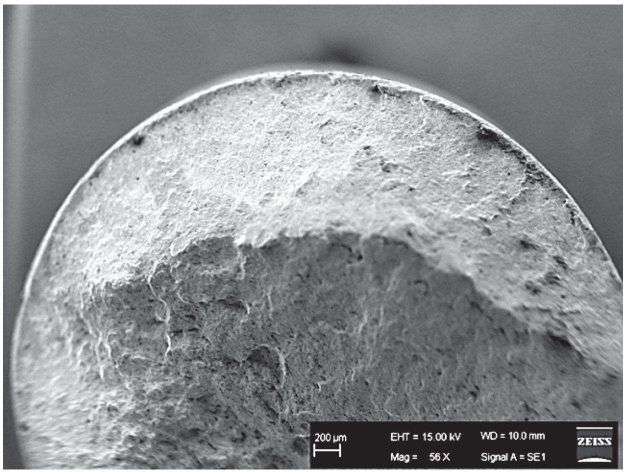

Figure 4 SEM image of crack surface

Table 2 **Mechanical values of specimen**

Yield Strength/ MPa	Tensile Strength/ MPa	Strain/ %
573	754	16,6

Tensile testing result is given in Table 2. Ultimate tensile strength, yield strength and strain are given in Table 2. Yield strength and ultimate tensile strength of material are sufficient to be used as construction steel. Strain value of the steel is 16,6 % which is acceptable in structural steels. Mn alloying in the steel increases yield and tensile strength of material.

Crack surface morphology is investigated with SEM and given in Figure 4. Crack surface shows cup and cone type failure. Elongated grains through deformation are pointing out ductile crack formation. Deformation traces is seen on the crack surface. Morphology investigation and mechanical values indicate ductile fracture features.

Steel slab shows macro cracks and Cu segregation on the slab surface. Inner parts of steel have homogenous Cu distribution. Machining of the steel surface eliminates Cu segregation and macro cracks on the surface. Smooth steel surface free of macro cracks and Cu segregation has no negative effect on mechanical properties. Crack propagation effect of Cu segregation is eliminated by machining of the steel surface. Ductile fracture confirms that machining eliminated Cu segregation effect.

High Mn amount in the steel promotes austenite formation that has higher Cu solubility than ferrite phase. Mn is also known as increasing the steel hardness with formation of solid solution. This effect decreases the Cu segregation and increases tensile strength to some extent.

CONCLUSION

Hot shortness in Cu containing steel is observed after hot rolling process. Surface segregation is found to be main reason for macro cracks on the steel surface. Intergranular cracks occurred during hot rolling process due to grain boundary segregation of Cu.

Machining of the steel surface eliminates Cu segregation and macro cracks thus more homogenous matrix is obtained according to initial status. Tensile testing results show satisfying mechanical properties for structural carbon steel. Ductile fracture is important to prevent unexpected failure of material. This technique can be used to evaluate Cu containing steels. Mn alloying increased steel strength and prevented excessive Cu segregation thus can be a solution in Cu containing steels.

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Note: The responsible for English language is Selçuk Yeşiltepe, Turkey