（＊掲載記事題目及び掲載頁は変更になる場合があります。）

Fundamentals of High Temperature Processes

Behavior of alumina inclusions just after deoxidation

M.WAKOH et al.

Many efforts have been made to remove non-metallic inclusions from molten steel, however, the required level of steel cleanness from steel users has become stricter year by year. Not only the way of removing the inclusions but also the way of keeping the inclusion size small are considered effective countermeasures for meeting the users' demand. Hence, it is important to investigate control factors governing the size distribution of inclusions in steel. From the viewpoint described above, the initial size distribution of alumina inclusions just after deoxidation reaction in steel has been studied by using a new sampling method with varying aluminum and oxygen contents in laboratory scale experiment. Two kilograms of steel was melted in a Tammann furnace at 1 873 K under an Ar gas atmosphere, then the carbon and oxygen concentrations were adjusted. The sampling method that enables to take a steel sample just after the addition of aluminum was used. The size distribution of alumina inclusions in steel samples was measured by using an electron probe micro analyzer with LaB_6 filament of an electron beam gun and with newly developed software for particle analysis. The result showed that the size distribution of alumina inclusions was affected by oxygen content in the steel, and that the growth of the inclusions during 1 s after the deoxidation was considered to be controlled by the oxygen diffusion.

(cf. *ISIJ Int.*, **47** (2007), 627)

Visualization of collision behavior of particles simulating inclusions in a turbulent molten steel flow and its theoretical analysis

Y.MURAKATA et al.

The separation of inclusions with sizes less than several micrometers is very difficult due to their slow terminal velocity. Thus, increasing the volume of inclusion is essential for accelerating the removal of inclusions, and several methods for enhancing collision frequency of inclusions have been proposed, hitherto. Their collision behavior, however, has not been directly observed yet. In this study, by using a water model, the collision rate of polystyrene particles simulating inclusions in a molten steel was quantified by direct observation of the particle collision behavior in a turbulent flow. The collision rate of the particles counted by use of an image analysis method was compared with a theoretical collision rate, which was calculated by substituting the turbulent energy dissipation rate obtained in a numerical analysis into the Saffman–Turner's equation. In the range with large turbulent energy dissipation rate beyond 0.06 m^2/s^3, the observed collision rates deviated above the theoretical values. In view of this, the Saffman–Turner's equation has been modified so that it can be applied to the range with large turbulent energy dissipation rate.

(cf. *ISIJ Int.*, **47** (2007), 633)

The role of Ca and Na ions in the effect of F ion on silicate polymerization in molten silicate system

Y.SASAKI et al.

For $CaO–CaF_2–SiO_2$ and $CaO–CaF_2–Na_2O–SiO_2$ systems, the effect of Na and Ca cation ions on the polymerization of silicate slags containing F ions and their structures are investigated by using molecular dynamics simulation. The substitution of F for O in the $CaO–SiO_2$ melts enhances the polymerization of the melt due to the formation of loosely bonded Ca–2F complexes. The substitution of Na ions for Ca ions without changing the total number of F, O and Si ions in the $CaO–CaF_2–Na_2O–SiO_2$ melts has a negligible effect on the distribution of silicate complex anions. For the $CaO–CaF_2–Na_2O–SiO_2$ system, the existence of the loosely bonded Ca–2F and Na–F complex are confirmed from the running coordination number variation. The relative amounts of the loosely bonded Ca–2F and Na–F complex in the $CaO–CaF_2–Na_2O–SiO_2$ system are depended on Na/Ca ratio. It is found that the loosely bonded Ca–2F and Na–F complexes in the $CaO–CaF_2–Na_2O–SiO_2$ melts are not randomly distributed but are clustered.

(cf. *ISIJ Int.*, **47** (2007), 638)

The coordination of F ions around Al and Ca ions in molten aluminosilicate systems

Y.SASAKI et al.

The structure of $CaO–CaF_2–Al_2O_3–SiO_2$ systems with various F/O ratios has been investigated by using molecular dynamics simulation to evaluate the effect of F ions on the polymerization of melts. F ions in the melt are found to be mainly coordinated to Ca ions but not to Al ions. The formation of loosely bonded Ca–2F complexes in the $CaO–CaF_2–Al_2O_3–SiO_2$ melts is confirmed since the cumulative coordination number for F around the Ca ion at around the equilibrated bond length is approximately 2. Due to the formation of Ca–2F complexes, Ca ions available to the network modifier are decreased so that the degree of the polymerization of Si units in $CaO–CaF_2–Al_2O_3–SiO_2$ system is increased. The amount of aluminate tetrahedra embedded in silicate three-dimensional network unit is gradually decreased by the substitution of F ions for O ions because the amount of the silicate three-dimensional network unit is increased due to the decrease of Ca ions available to the network modifier.

(cf. *ISIJ Int.*, **47** (2007), 643)

Combustion synthesis of TiC–Fe composites under the action of an electric field

K.FENG et al.

Using thermal simulation equipment, the combustion synthesis process of the compact of 55wt%(Ti+C)–45wt%Fe was studied. The results show that the ignition temperature of Fe–Ti–C system can be decreased greatly under the action of electric field and great thermal density. Before heating up to 350°C, although there is no reaction takes place in the system, the microstructure of the system changes with the temperature; During heating from 350–470°C, a thermal explosion phenomenon appears. Especially in the earlier stage of the combustion reaction, the dominant reaction is the one synthesized TiC; As the temperature up to 670°C continuously, $Ti_{(s)}+C_{(s)}=TiC_{(s)}$ reaction takes place accompanying with $2Fe_{(s)}+Ti_{(s)}=Fe_2Ti_{(s)}$, and the conversion degrees of these reactions are increasing with the temperature increasing gradually. However, a part of Fe_2Ti will be decompounded with the temperature increasing further, as a result, $Ti_{(s)}+C_{(s)}=TiC_{(s)}$ will go on because of the addition Ti. Consequently, the synthesized product consist of Fe, TiC and a little of Fe_2Ti, and ultrafine TiC particles distribute in the Fe matrix uniformly.

(cf. *ISIJ Int.*, **47** (2007), 648)

Ironmaking

Factors influencing particulate emissions during iron ore sintering

D.DEBRINCAT et al.

Controlling particulate emission from a sinter strand is important to minimizing its impact on the environment. Several factors influencing particulate emission from an iron ore sinter strand were investigated in the current work using a laboratory scale sinter pot. A blend fairly typical of that currently used in the Asia Pacific region, as well as another containing 30 mass% Marra Mamba ore that could represent a future ore blend were used. It was established that most of the particulates emitted were less than 1.18 mm and were mostly from the calcination and dried zones of the bed. In addition, most particulates were released from the bed after the wet zone in the bed had ceased to exist. This work suggests mix moisture and coke rate had a significant impact on particulate emissions. Increasing moisture from 5.5 to 9.0 mass% decreased particulate emission while increasing coke content from 5.5 to 7.5 mass% increased particulate emission. Therefore when altering the ore blend changes in mix moisture and coke rate may also need to be accounted for when evaluating the impact on particulate emission. It was also found that particulate emission could be decreased by decreasing sintering suction just before burn-through.

(cf. *ISIJ Int.*, **47** (2007), 652)

Numerical simulation of effect of tuyere angle and wall scaffolding on unsteady gas and particle flows including raceway in blast furnace

T.UMEKAGE et al.

We have performed the numerical simulation for the particle and gas flows in the raceway region in a blast furnace of which dimension is almost the same as that of the commercial blast furnace using Distinct Element Method for the computation of the multi-body interaction among coke particles, Hard Sphere Model for two body interaction of powder particles based on Direct Simulation of Monte-Carlo Method, and Finite Difference Method for the numerical analysis of Navier–Stokes equations with the interaction terms between gas and particles for the gas flows. In the present simulation we have calculated the particle and gas flows in the raceway regions in which tuyere angles are 0, 3, 7 and 11 de-

gree downward. The downward inclination of tuyere means that the air injects to the higher pressure side. This would stabilize the air flow and the raceway would become stable. However if the inclination angle is too high, the flow becomes unstable by various conditions near the bottom of blast furnace. The coke particle flow rate from the center region of blast furnace and its flow width increase with increasing the tuyere downward angle from the horizontal and attains the maximum value at near 7 degree. It means that the coke particle flow becomes widely uniform at about 7 degree tuyere angle except the region near the furnace wall.

We have also calculated the effect of scaffolding on the furnace wall on the particle and gas flows. The coke particle flow distributions with scaffolding on the wall become narrower. The scaffolding is nearer to the raceway, the effect of that becomes stronger. The raceway is not spherical and becomes unstable in cases with scaffolding on the wall. The coke particle velocity becomes higher by the narrow coke particle flow distribution caused by the existence of the scaffolding on the wall and it concentrates coke particles on the upper part of raceway near the furnace wall. The coke particle flow is dammed by the scaffolding and the wide area in which the coke particle velocity is very low is formed on the scaffolding. The gas flow distribution with scaffolding becomes non-uniform, particularly in the area between the softening melting cohesive zones and the scaffolding due to their interaction. The gas flow is also dammed up by the scaffolding and softening melting cohesive zones. The existence of scaffolding near softening melting cohesive zones strongly affects the gas flow.

(cf. *ISIJ Int.*, **47** (2007), 659)

Reaction behavior of dolomite accompanied with formation of magnetite solid solution in iron ore sintering process

K.HIGUCHI et al.

To discuss assimilation of dolomite with sinter mixture and the influences of dolomite use on the performance and on sinter quality, pot tests and small scale assimilation tests have been conducted. In particular, a microstructural evolution during sintering with using dolomite was focused on. Dolomite with mean size of 1 mm showed fairly good performance in pot tests. Using excessive fine or coarse dolomite resulted in loss of strength due to different mechanisms. Assimilation rate of dolomite was in the range between limestone and serpentine. Fluxes with large particle size above 1 mm tended to influence on microstructural evolution during sintering. Reaction behavior of dolomite during sintering consisted of 4 steps, calcination, formation of magnetite s.s by solid-state diffusion, formation of calciumferrite melt and formation of magnetite by reaction between MgO and calciumferrite melt. The last step was associated with the decrease in strength or yield of sinter. Difference in the nature of the magnetite s.s formed by two different mechanisms seemed to be related to the difference of sinter quality. In comparing reactions of dolomite and serpentine, microstructural evolution process differed by properties of formed melt during assimilating, reducible conditions in equilibrium state, fluidity and diffusion rate of Mg^{2+}. Results of plant trials to examine proper amount of use and size distribution of dolomite showed that dolomite with 1.0 mm mean size could replace dunite or Ni-slag as MgO-bearing fluxes without significant worse effect in the limited amount of use.

(cf. *ISIJ Int.*, **47** (2007), 669)

Steelmaking

Flow dynamics in thin slab molds driven by sustainable oscillating jets from the feeding SEN

E.TORRES-ALONSO et al.

Sustainable oscillations of discharging jets from a two-port SEN in a thin slab caster were studied using various experimental water-modeling techniques and mathematical simulations *via* a combination of Reynolds Stress Model and Volume of Fluid Model to follow interface dynamics of liquid phase. A dynamic distortion of low frequency was observed on fluid flow. This distortion enhances the permanent oscillations of discharging jets and finally produces large gradients of Reynolds stresses at their boundaries with the surrounding flow. Thus high strain stresses derive into large gradients of dissipation rates of kinetic energy through the jets giving place to large and small eddies which transport energy to the free bath surface and refine the flow structure located below the tip of the SEN, respectively. As a final result non-symmetric flows with high meniscus instability are produced independently of casting speed and mold size. These results are a bottom line reference to design future SEN's for thin slab casters with improved performances.

(cf. *ISIJ Int.*, **47** (2007), 679)

Electrochemical deoxidation of molten steel with application of an oxygen permeable membrane

H.W.KOO et al.

The deoxidation of molten steel has been studied by employing an electrochemical cell which utilizes a solid-oxide electrolyte. This technique enables deoxidation of liquid steels without leaving deoxidation products in the steel. Y_2O_3-stabilized ZrO_2 (YSZ) is used as an oxygen-permeable membrane due to its reasonably high mixed-ionic and electronic conductivity and thermal stability at elevated temperature in low oxygen partial pressure (P_{O_2}). In order to investigate the rate-determining steps involved in this electrochemical deoxidation process, the oxygen-permeation experiment using a YSZ disk is performed to measure the oxygen flux as a function of P_{O_2} and temperature. The measured oxygen flux is about one order of magnitude smaller than the estimated value from Wagner equation that describes permeation under bulk-diffusion limit. Thus, oxygen permeation is mostly controlled by surface-exchange kinetics even at high temperature (~1 600°C) in reducing atmosphere. In the experiment of deoxidation of molten steel using a YSZ tube, the deoxidation rate is largely dependent on the surface-exchange kinetics as well. The deoxidation rate is much smaller than that calculated under the assumption of bulk-diffusion limit. Based on these results, the surface modification of YSZ is investigated as a way to enhance the deoxidation kinetics. Both surfaces of the membrane are coated with porous YSZ ($Zr_{0.84}Y_{0.16}O_{2-\delta}$), GDC ($Ce_{0.8}Gd_{0.2}O_{2-\delta}$) and LSC ($La_{0.7}Sr_{0.3}CrO_{3-\delta}$) during oxygen permeation experiment in the gas phase. During the deoxidation experiment in the steel melt, only the permeate side is coated with Pt, Mo-YSZ cermet and LSC. The oxygen permeation rate of YSZ drastically increased with coating. The increase also depended on the coating materials. Thus, it is shown that the oxygen permeation through the membrane is mostly controlled by the surface-exchange kinetics. Similar trend can be seen in the deoxidation experiment, confirming the surface-exchange kinetics limit.

(cf. *ISIJ Int.*, **47** (2007), 689)

Behavior of inclusions in deoxidation process of molten steel with *in situ* produced mg vapor

J.YANG et al.

In the deoxidation process of molten steel with magnesium vapor produced *in situ* by aluminothermic reduction of magnesium oxide, the formed inclusions are usually small in size and of spherical shape. They tend not to aggregate and form cluster. The MgO content in the inclusions decreases, while the SiO_2 content increases with the progress of experiment. Larger inclusions are removed by floating up with the rising bubbles more easily and the fine inclusions tend to remain in the melt. The oxygen concentrations originated from the inclusions can be reasonably explained from the experimental analysis ones.

By use of the MgO porous immersion tube, deoxidation proceeds slowly at the initial stage, but it continues until the later stage of experiment, in contrast to that using the dense Al_2O_3 immersion tube. The formed inclusion number per unit area has a larger value than that with the dense Al_2O_3 tube. The number of inclusions also increases with increasing the initial oxygen concentration and dividing pellets charging into several portions. When the carrier gas flow rate is large, the number of inclusions tends to increase at the later stage of experiment due to the strong involvement of inclusions from the melt surface into the melt.

In the present deoxidation process, it is considered that the rapid removal of larger inclusions by rising bubbles is beneficial to produce high cleanness steel, while the remaining fine inclusions is helpful for the grain refinement of steel during the solidification and phase transformation process.

(cf. *ISIJ Int.*, **47** (2007), 699)

Surface Treatment and Corrosion

Effect of laser gas nitriding on the microstructure and corrosion properties of Ti–6Al–4V alloy

R.S.RAZAVI et al.

Laser surface melting of Ti–6Al–4V alloy under a pure nitrogen environment of 30 L/min gas flow rate, was carried out with 200–600 mJ laser beams, produced by a Nd-YAG pulsed laser at 5 mm defocused distance, and 0.5–3 mm/s sample traverse ve-

locities. The microstructure, hardness and corrosion behaviour of the nitrided samples were examined, using scanning electron microscopy, X-ray diffractometry (XRD), microhardness measurements across the workpiece cross-section and anodic polarization tests in 2 M HCl solution.

The microstructures consisted mainly of a thin continuous layer of titanium nitride followed by nearly perpendicular dendrites, and below this, a mixture of small dendrites and large needles, which had a random orientation. The denderitic structure was the TiN phase, and the needle phase and the phase of the matrix between the dendrites were nitrogen-enriched α'-Ti. The density of TiN dendrites decreased gradually towards the interface between the nitrided layer and the substrate. The melted zone showed a range of hardness of between 400–1300 Hv, the hardness being found to be related to the dendrite populations. An improvement in corrosion behaviour, associated with the presence of a good TiN coating, was observed. Also, the improved pitting corrosion resistance is obtained due to the microstructural changes after laser treatment.

(cf. *ISIJ Int.*, **47** (2007), 709)

A study on the corrosion resistance of Cr-bearing rebar in mortar in corrosive environments involving chloride attack and carbonation

S.-H.TAE et al.

Nine types of reinforcing steels having different Cr contents were placed in mortar simulating environments involving chloride attack, carbonation, and combined deterioration and subjected to corrosion-accelerating test for fundamental research on the corrosion resistance of Cr-bearing rebars in corrosive environments where reinforced concrete structures are to be constructed. The polarization resistance and corrosion potential of Cr-bearing rebars were then measured at temperatures of 60, 40, and 20°C to investigate their electrochemical properties in corrosive environments. Their corrosion area and average corrosion rate at the end of 40 cycles of corrosion-accelerating testing were also calculated to investigate their corrosion resistance.

As a result, the corrosion resistance of Cr-bearing rebars was found to increase as their Cr content increases in all corrosive environments, and the excellent corrosion resistance of Cr-bearing rebars with Cr contents of 5% or more and 7% or more was confirmed in uncarbonated and carbonated environments, respectively, with a chloride ion content of 1.2 kg/m^3.

(cf. *ISIJ Int.*, **47** (2007), 715)

Transformations and Microstructures

Effect of carbon on the shape memory mechanism in FeMnSiCrNi SMAs

N.V.CAENEGEM et al.

Fe–Mn–Si–Cr–Ni alloys are Fe-based shape memory alloys (SMA), which make use of the $\gamma \leftrightarrow \varepsilon$ stress-induced martensitic transformation. In the present study, the effect of C addition on the shape memory effect was reported. The characterization of the martensitic transformation and the phase components was carried out by using light optical microscopy, X-ray diffraction, internal friction measurements and transmission electron microscopy (TEM). C is often mentioned to improve the shape memory behaviour. Present results show, however, an opposite effect. It is believed that the relative position between the deformation temperature and the Ms temperature for the two alloys is of key importance when looking for an explanation for the presented experimental results. The lower Ms temperature for the high C alloy causes more slip and less transformation of the austenite. The microstructural characterization showed a lower amount of formed ε martensite during deformation for the high C alloy.

(cf. *ISIJ Int.*, **47** (2007), 723)

TTP diagrams of Z phase in 9–12% Cr heat-resistant steels

K.SAWADA et al.

Time-Temperature-Precipitation diagrams of Z phase were investigated in crept samples of 9–12% Cr heat-resistant steels. The Z phases were formed around the prior austenite grain boundaries at 823 K, 923 K, and 973 K—temperatures similar to the 873 K reported in a previous paper. The time required for Z phase formation was shorter in higher Cr steels, indicating that to avoid Z phase formation the Cr content of the steel should be reduced as far as possible. The beginning of Z phase formation did not consist with an inflection point on the stress–rupture curve in all steels. Z phase formation could promote the degree of creep strength degradation at long-term region. The average chemical composition in the Z phase depended on the temperature: the Nb content of the Z phase was lower at lower temperatures. The average chemical composition of the Z phase changed during creep; the Cr and Nb contents of the Z phase increased and decreased, respectively, during creep exposure. The size and number density of the Z phase at 823 K, which is the maximum operating temperature of the next generation of fast breeder reactor components, were small in contrast with those at 873 K. The influence of Z phase formation on creep strength would not be large up to about 50 000 h at 823 K since most of MX cabonitrides would not disappear.

(cf. *ISIJ Int.*, **47** (2007), 733)

Reactive diffusion between solid Fe and liquid Zn at 723 K

R.KAINUMA et al.

Reactive diffusion between solid Fe and liquid Zn was experimentally examined using Fe/Zn diffusion couples prepared by an immersion technique. Using this technique, a pure iron sheet was immersed in a molten pure Zn bath with a constant temperature of T=723 K (450°C) for various times up to t=7.2×10^3 s (2 h). The microstructure of the cross section of the Fe/Zn diffusion couple was observed by scanning electron microscopy, and the chemical composition of each phase was determined by electron probe microanalysis. Interface concentrations of Fe for the ζ-$FeZn_{13}$ and δ-$FeZn_{7-10}$ phases at the ζ/δ interface, $c^{\zeta\delta}$ and $c^{\delta\zeta}$, and for the liquid-Zn (L) phase at the ζ/L interface, $c^{L\zeta}$, determined from the diffusion couples were found to be extremely higher than the corresponding equilibrium values, especially in the early stage of t<300 s, and the difference gradually decreased during immersion. The deviations from the equilibrium values for the $c^{\zeta\delta}$ and $c^{L\zeta}$ were proportional to the interdiffusion flux across the ζ phase layer.

(cf. *ISIJ Int.*, **47** (2007), 740)

New Materials and Processes

Alloy design and properties of new $\alpha+\beta$ titanium alloy with excellent cold workability, superplasticity and cytocompatibility

T.HIRANO et al.

Alloy designing and evaluation of various properties of new $\alpha+\beta$ type titanium alloy with excellent cold workability, superplasticity, and cytocompatibility were conducted. Alloy designing was performed by investigations of the effects of O, Al, Mo, Fe, and Nb contents on cold workability of the alloy with a basic composition of Ti–4.5%Al–4.5%Nb–2%Fe–2%Mo. Use of β stabilizing elements such as V, Ni, or Cu was avoided for biocompatibility. Cold workability was evaluated on the basis of a critical rolling reduction for onset of cracking, hardness under as solution treated condition and hardness variations with a cold rolling reduction. Excellent cold workability was obtained by enhanced thermal and mechanical stabilities of β phase and by lowered hardness of α phase in the $\alpha+\beta$ two-phase microstructure. Newly developed alloy Ti–4.5%Al–6%Nb–2%Fe–2Mo showed the β transus of 1 156 K, a critical rolling reduction over 60%, and yield strength in recrystallization annealing of 910 MPa. An extremely fine $\alpha+\beta$ two-phase microstructure with α grain size of approximately 1 μm was evolved by annealing at 1 048 to 1 073 K, and a superplastic elongation value of around 3 000% was obtained by tensile testing at these temperatures. New alloy showed an excellent cytocompatibility in a cell culture test using L929 cells, yielding a higher value of cell viability over Ti–6%Al–4%V and Ti–6%Al–7%Nb alloys.

(cf. *ISIJ Int.*, **47** (2007), 745)

Social and Environmental Engineering

Estimation of the change in quality of domestic steel production affected by steel scrap exports

Y.IGARASHI et al.

The total crude steel production in Asian countries was 500 million t in 2004, which accounted for 47% of the total crude steel production in the world. There has been a large demand for steel scrap in Asian countries; Japan exported 2.5 million t of steel scrap to China, 1.91 million t to Korea and 0.9 million t to Taiwan in 2003. According to our previous studies, steel scrap generation in Japan will increase until 2030. A future change in steel scrap demand from Asian countries will greatly influence the amount and quality of Japan's steel scrap domestic consumption and exports. In this work, the change of quality was estimated for domestic steel production (electric arc furnace steel for buildings and con-

struction) by the influence of steel scrap exports. A method based on the population balance model and material pinch analysis was applied to assess both the quality of domestic steel production and steel scrap consumption. Previous data concerning the quality (copper concentration) of steel scrap and the recovery ratio of steel scrap from post consumer products were updated. It was found that the quality requirements of steel scrap to other countries could have a large influence on the quality of domestic steel.

(cf. *ISIJ Int.*, **47** (2007), 753)

Dynamic material flow analysis for stainless steels in Japan-Reductions potential of CO_2 emissions by promoting closed loop recycling of stainless steels

Y.IGARASHI et al.

Stainless steels are corrosion resistant alloys that are widely used in consumer goods and industrial equipment. Stainless steels contain scarce and energy intensive elements such as Ni, Cr, Mo, which means that closed loop recycling is preferable for sustainable stainless steel production. However, some stainless steels are not separated from ordinary steel scraps in the recycling processes and cannot be recycled as "stainless steel". The objective of this study is to analyze the dynamic substance flow of stainless steels in Japan and assess the potential for reducing CO_2 emissions by promoting closed loop recycling of stainless steels in the future. First, the authors analyzed material balance of input elements, *i.e.* Fe, Ni and Cr, in the production of stainless steels in 2002 to determine which aspects associated with the material flow of stainless steel cannot be elucidated from available statistical data. The amount of post-consumer stainless steel that would enter into society in the future was estimated by employing a Population Balance Model (PBM). It was found that only 2% of post-consumer stainless steel containing Fe–Cr alloys was collected as stainless steel scraps while the remainder was collected as ordinary steel scrap. Conversely, approximately 95% of post-consumer stainless steel consisting of Fe–Ni–Cr alloys was collected as stainless steel scrap. A CO_2 emission reduction potential for a 1% increase in the closed loop recycling of stainless steel scraps of Fe–Cr alloys was estimated at 75 000 t/year by Life Cycle Assessment (LCA).

(cf. *ISIJ Int.*, **47** (2007), 758)