Effect of N_2 and CO_2 additions on arc voltage and steel composition during argon plasma heating of steel melts

D. Neuschütz and A. Stüber

Lehrstuhl für Theoretische Hüttenkunde, Rheinisch-Westfälische Technische Hochschule Aachen, D-52056 Aachen, Germany

Abstract

Argon-plasma heating of liquid steel in the tundish directly before solidifying the steel in continuous casting machines is increasingly carried out to improve product quality and product yield. A pilot investigation was carried out with a 600 kW two-torch AC plasma furnace to find feasible methods to increase the arc voltage by adding di- and triatomic gases to the furnace atmosphere (argon) and to quantify the metallurgical consequences of these additions. In a number of test runs the steel melts were stirred by argon gas bubbling from the bottom. The addition of 20% N_2 and 20% CO_2, respectively, raised the arc voltages above unstirred steel melts from 100 V to 120 V (N_2) and 175 V (CO_2). When argon bubbling was applied, the arc voltages dropped evenly by 25 V: Metal droplets formed by bubble bursting penetrated into the arcs, evaporated and raised the arc conductivity. The degree of penetration of the furnace gases into the plasma arcs was 10 to 12%. The gas additions inevitably led to a certain pickup of nitrogen or oxygen by the melt, but in large-scale operation, the changes in steel analysis will mostly remain well below the tolerance limits.

1. Introduction

Heating liquid steel in the tundish with argon-stabilized plasma arcs is one example of the increasing importance of mobile and inert heating systems in metallurgy [1]. Plasma ladle furnaces represent another field of growing application in steelmaking. Presently, the heating power of such plasma systems is limited by the torch current which is, for acceptable electrode lifetimes, around 8 to 12 kA [2]. A power increase may be achieved by adding di- or triatomic gases to the plasma-gas argon through the resulting increase of the arc voltage [3,4]. Such additions are faced with two serious constraints: Since the lifetime of hot electrodes which are the only choice to realize high amperages is drastically shortened in the presence of other than monatomic gases, these other gases should only be added in a manner to penetrate into the plasma arc downstream the torch electrode. The second constraint is the metallurgical requirement to keep any possible changes of the steel composition within the tolerance limits. With these boundary conditions in mind, trials were carried out in a pilot plasma furnace to increase the heating power by adding nitrogen, oxygen, air, or carbon dioxide to the furnace atmosphere and to check the metallurgical consequences.

2. Experimental

The pilot plasma furnace, Fig. 1, was equipped with two plasma torches containing thoria-doped tungsten electrodes and operated in the AC mode without bottom electrode [5]. The position of the torches could be varied with respect to the melt surface. Typically, 200 to 300 mm arc length between torch electrodes and melt surface were chosen. The arc currents were 1.0 to 1.4 kA. In the furnace bottom, two porous plugs could be installed for bottom-stirring the melt with totally 170 (max 220) l_{STP} Ar/h. Each plasma torch was run with 10 m^3_{STP} Ar/h, while the addition of N_2, air or CO_2 was carried out through 4 holes on the furnace periphery, see Fig. 1. The amounts of gases added are given in percent of the total gas atmosphere before chemical reactions take place. The pressure in the furnace was held at +5 to 10 mbar.

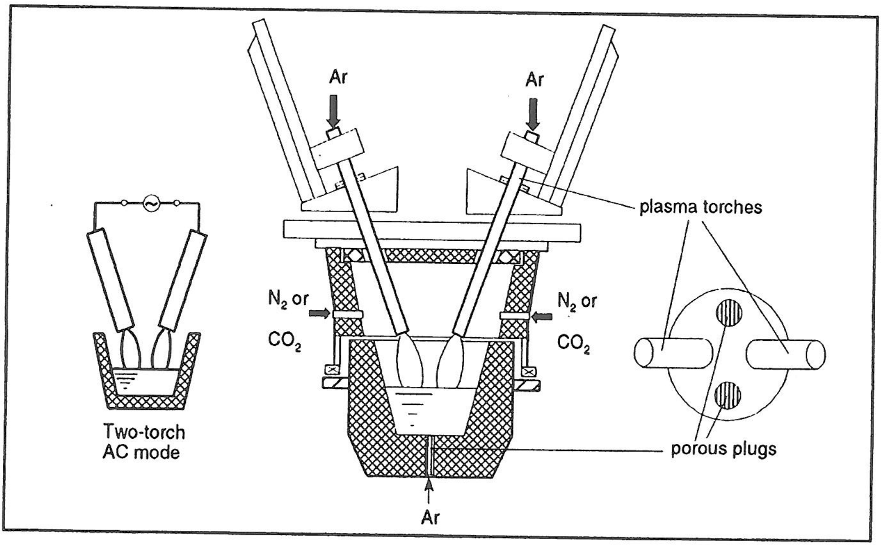

Fig. 1: Plasma furnace for heating liquid steel in the two-torch AC mode with provisions to add N_2 or CO_2 to the furnace atmosphere and to stir the melt by injecting Ar through the bottom

The offgas was analyzed in a quadrupole mass spectrometer. Melt samples were taken intermittently by immersing a probe through the lid. For sampling plasma heating was interrupted. The tests were carried out with steel heats of 150 kg and, in the case of bottom-stirring of 225 kg. The steel compositions at the beginning of plasma heating were in the range 0.04-0.08% C, 1.5-2.2%Si, 1.0-1.3% Mn, 0.1-0.2% Al, 30-70 ppm N, 30-50 ppm O, and 20-70 ppm S. Before starting the actual tests, the furnace was flushed with Ar until the offgas contained > 99% argon and the scrap melted with pure argon plasma.

3. Results

3.1 Effect of gas additions on arc voltage

The results of plasma arc voltage measurements as a function of arc length (measured as distance between torch electrode tip and melt surface in torch direction) and gases added into the furnace are given in Fig. 2 for unstirred and for bottom-stirred melts. In the range of arc lengths investigated, the arc voltages varied linearly with arc length. The addition of di- or triatomic gases to the furnace always led to an increase of the arc voltage as compared to pure argon operation. At 30 cm arc length, the absolute voltages observed above unstirred steel melts were (± 5V): 100% Ar:100 V, 5% O_2+95% Ar: 110 V, 20% N_2+5% O_2+75% Ar: 116 V, 20% N_2+80%Ar: 120 V, 20%CO_2+80%Ar: 175 V. With 25% dry air, the voltage increase observed was somewhat lower than expected. An explanation has not yet been found. Above steel melts stirred by argon bubbling from the bottom, the arc voltages were found to be definitely lower. The corresponding values were: 100% Ar: 75 V (-25 V), 20% N_2+80% Ar: 95 V (-25 V), 20% CO_2+80% Ar: 150 V (-25 V).

3.2 Effect of bottom stirring on arc voltage

From Fig. 1, the influence of purging the steel melt was found to be a reduction of the arc voltages, at 30 cm arc length, by 25 V in all cases. Fig. 3 gives more detailed results for unstirred and stirred melts. Above 30 cm length, the arc voltages showed a tendency to become constant or even decrease again with arc length, which results from short-circuiting of the two arcs above the steel melt. The voltage decrease by argon bubbling depends on the arc length but is the same for the cases of N_2 and CO_2 addition. Iritani et al. [3] reported arc voltages to be lower on steel melts than on graphite blocks for an argon plasma heating system explaining this effect by iron evaporation in the arc roots on the steel surface. In fact, iron vapor in the argon plasma gas raises the electrical conductivity of the arc drastically [6]. The present results suggest that rather than by primary iron evaporation on the melt surface this effect is initiated by the formation of very fine iron droplets when argon bubbles arrive at the melt surface and burst. Some of the fine droplets formed by bubble bursting penetrate into the arc, evaporate and raise the arc conductivity. The phenomon known as "bubble bursting" and first described by Gleim [7] has been identified to play a major role in the formation of steelmaking dusts [8].

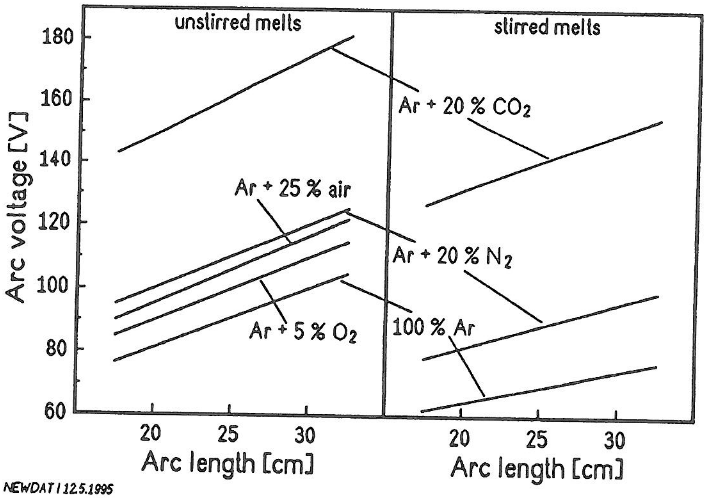

Fig. 2: Plasma arc voltage versus arc length during heating of liquid steel melts: Effect of di- and triatomic gases injected into the furnace with respect to pure argon operation, and effect of melt stirring by Ar bubbling.

Bubble bursting could also be observed in a test run when the melt was not stirred: When 25% dry air were added, the oxygen as a very surface-active element quickly formed a barrier against nitrogen desorption on the melt surface. Therefore, the steady nitrogen pickup of the melt via the plasma arcs led to supersaturation in the liquid steel and to nitrogen bubble formation ("boiling"), which could be observed optically. At the same time the arc voltage dropped suddenly by roughly 10 V, Fig. 4.

3.3 Metallurgical effects

The addition of 20% N_2 to the furnace atmosphere caused the nitrogen content of the melt to rise within 50 to 80 min up to a steady-state value which in the case of low oxygen and sulfur contents amounted to $[N]_s$ = 170 ppm. The kinetics of nitrogen transfer could well be described by the model derived previously [9,10]. The steady state is reached when the rates of nitrogen absorption in the arc attachment areas and of nitrogen desorption from the arc-free melt surface become equal.

In the case of sufficient oxygen pickup (addition of air), the desorption of nitrogen was prevented completely while its absorption from the plasma arc continued unchanged leading to a steady-state concentration of 530 ppm, when the melt was sufficiently supersaturated to form N_2 bubbles, see Fig. 4.

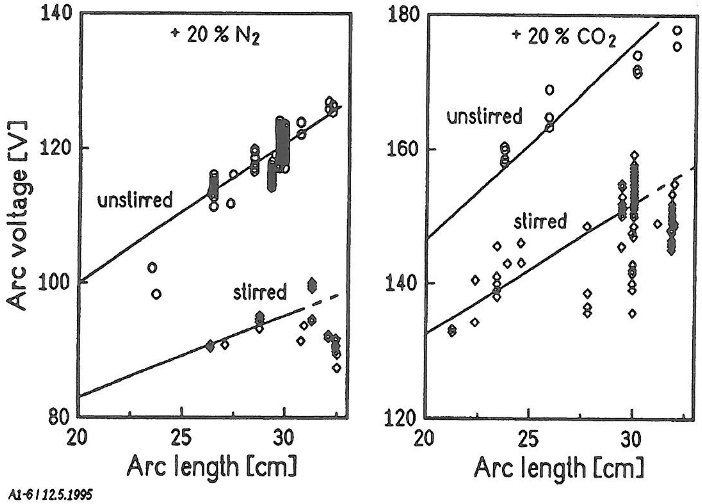

Fig. 3: Comparison of plasma arc voltages over steel melts without and with Ar bottom stirring.

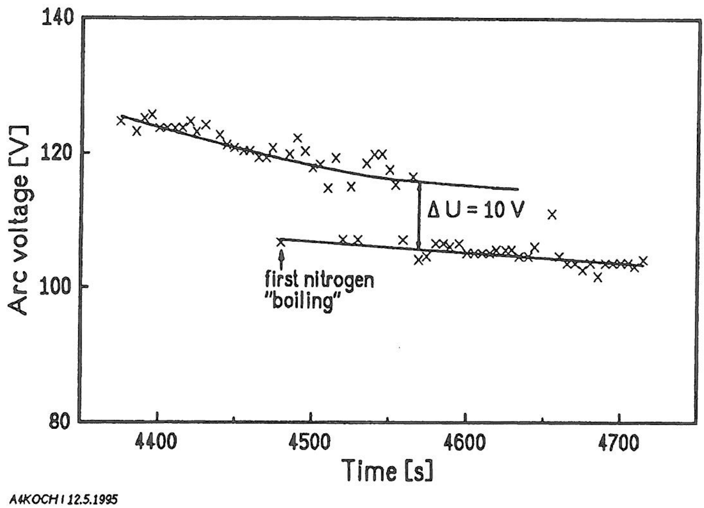

Fig. 4: Sudden Arc voltage drop in connection with N_2 bubble formation in N-supersaturated steel melt. Test run conducted with 25% air added to furnace. No bottom stirring.

In the presence of CO_2, a certain burn-off was observed in the melt for Al, and sometimes Si and Mn. During the first minutes of plasma heating, oxygen was transferred to the melt not only via the plasma arcs but also across the arc-free melt surface. Within 30 minutes, a thin slag layer would form which restricted the further oxygen absorption to the arc attachment areas. In that stage the CO concentration of the furnace offgas was measured to be 1.8-2.3%. Thus, about 10% of the CO_2 blown in the furnace reacted with the melt. From steel analyses the total burnoff during that stage was calculated yielding a CO_2 consumption of 12%. Assuming that all CO_2 having penetrated into the plasma arcs will react with the steel melt, we arrive at a degree of arc penetration of gases fed into the furnace atmosphere of 10 to 12%.

The burnoff rate - expressed in terms of Al oxidation - during plasma-heating with 20% CO_2 fed to the furnace was found to be 30 ppm Al/min after formation of a slag layer. The corresponding burnoff rate in a 30-t tundish equipped with a 1.4 MW plasma-heater (plasma-gas flow 40 m^3_{STP}/h) was estimated to be less than 1 ppm/min.

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