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APPLICATIONS OF BLAST FURNACE VISUALIZATION AND SIMULATION TECHNOLOGY[1]

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Abstract
Blast furnace visualization and simulation technology are used for monitoring the BF burden charging process and operation status to guide blast furnace operation. Laser grid and laser scanning are used for burden filling study before starting a newly built or relined furnace. Falling burden trajectories and the configuration of the burden surface can be obtained and used as the input of a simulation model. Laser detector is used for online observation and measurement of burden profile during furnace operation. Simulation model of burden distribution is used to simulate furnace charging and burden descending process. Thickness distribution of burden layers and O/C curves can be calculated from the model. BF top video camera and thermal camera are applied to on line observe furnace burden surface situation and burden charge equipment. It can also provide operators adequate information including furnace top gas distribution and detect real time irregular phenomena inside the furnace. Tuyere camera is used to monitor the working status and PCI situation in front of every tuyere with images and diagrams displayed in the control room. At present, blast furnace visualization and simulation technology is applied on more than 450 BFs at the mainland China and Taiwan. Besides, more than 20 blast furnaces abroad are also using this technology.
Key words: Blast furnace visualization; Simulation model; Video and thermal camera; Laser technologies.

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Introduction

Blast furnace is a kind of closed reactor for liquid pig iron production. Operators used to understand and analyze furnace status and run the furnace only rely on conventional measurements of temperature, pressure, off gas flow rate and gas composition etc. The internal image inside the furnace could not be observed in the past, so to operators blast furnace is a kind of black box.
University of Science and technology Beijing (USTB) and Shengwang Pioneer Tech. Corporation Beijing (BSW) have jointly developed several visualization technologies applied for BF internal monitoring to observe burden charging and inside furnace processes to guide BF operation. These help BF operators to know how burden charge equipment running and understand burden distribution situation to have BF operation switched from inactive to active. This is significant for BF operators to open the black box.

1. Filling Study using laser technology

In order to fully utilize the advantages of bell-less top, some basic information about burden distribution should be studied to guide BF charging operation. Steel bars and steel wire network used to be applied to measure burden falling trajectories. Measured results were not very satisfied (1) however and it was a really hard work for operators to get inside the furnace to prepare steel wire network. Furthermore, this kind of measurement takes quite long time, so it is not effective.

Laser technology was developed in order to enhance efficiency and accuracy for filling study. Laser beams form a network as a reference coordinates for burden falling trajectory measurement. Laser scanner is used to scan burden surface profile during burden filling process for a newly built or relined BF.
Two laser emitters are installed oppositely at BF top to form laser beam network inside the furnace, see Fig. 1. During burden filling process for a newly built or relined furnace, video cameras are used to obtain images of falling burden stream passing through the laser network. Computer is used to process the images of burden stream intercepting laser network, and then different burden stream curves and data can be obtained under different chute angles. Laser scanner is used to get burden surface profile and relative data.

Laser grid measurement was firstly applied to measure burden stream trajectories and got success in April 2005 in a newly relined 4350m^3 BF at BaoSteel. Filling study using laser technology was carried out in August 2009, on “E” BF at USSC Hamilton Works. Results of burden falling trajectories are shown in Fig. 2 and that of burden surface profiles are shown in Fig.3 (2).

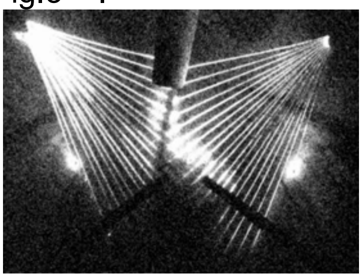

Fig1 Burden stream passing through laser grid

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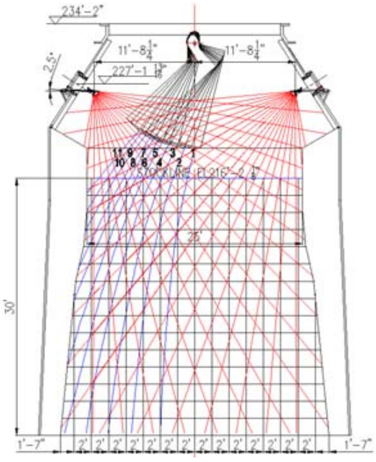

Fig2 coke falling trajectories

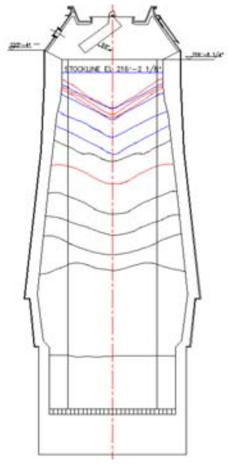

Fig3 burden surface profiles

2. Burden distribution simulation model

BF burden distribution simulation model is based on data obtained from laser measurements during filling study. Human friendly computer interface has been established. The main goal of this model is to obtain location, thickness and shape of ore and coke layers. Ore/coke curves along furnace radius can be obtained through calculations.

The characteristics of this simulation model are as following:

- Simulate the profile of upper lump ore and coke layers of BF burden column, with an assumption that burden is uniformly distributed along the stack circumference;
- Take the burden as many discrete tiny elements. With very little time interval, the burden charging process is treated by a 2D dynamic simulation model;
- Considering the stack declining angle, when burden is descending, the thickness of burden layer decreases. This consideration is more perfect than the assumption that stack is a cylinder type and burden profile is fixed with burden descending;
- Consider coke sliding effect, together with the shape and location of initial burden profile;
- Simulate all phenomena including skip loading and unloading, stockline ruler movement, burden falling stream trajectories and stream widths, burden surface configuration, burden descending and the formation of mixed burden layer etc;
- Ore/coke ratio curves can be calculated and plotted along with different radius directions. The characters of current burden distribution can be reflected accurately.

With this model, calculated results and plots can reflect real time situation of a burden charge process.

Simulation model has been applied at No. 8 BF of Fairfield plant [3], US Steel. Good results were obtained as follows:

1) Models can be run off line also. Operator can use the off line module to simulate different charging regimes and carry out rational charging operation to improve

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furnace permeability and enhance productivity (See Fig.4).

2) Through the on line module running the simulation model with the acquisition of burden charging parameters automatically and continuously, burden distribution practice can be predicted and all information can be recorded at real time in a relative data base. When a wrong skip loading occurred once in the BF No.8, Fairfield plant, the running model detected it right away and, at same time, countermeasures were taken, avoiding a possible accident. This model has been applied in daily routine. All burden charging regimes have been put into different modules. Operators can use these modules to predict different operation results and make their decision fast and accurate to run the BF smoothly.

"E" BF in USSC Hamilton Works applies the simulation model derived through the data obtained during filling study and obtained good results (see Fig. 5). Gas utilization ratio was enhanced from 43% to 46% and fuel ratio dropped by 50 lb/NTHM. BF productivity was improved remarkably [(2)].

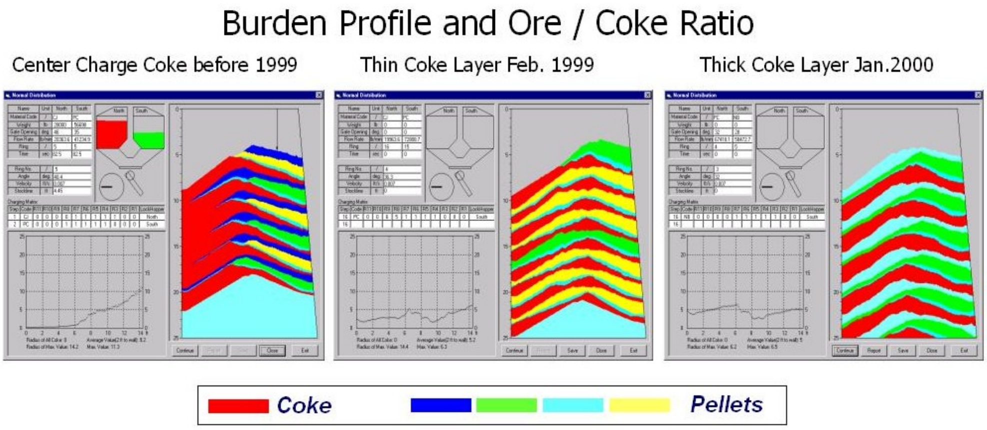
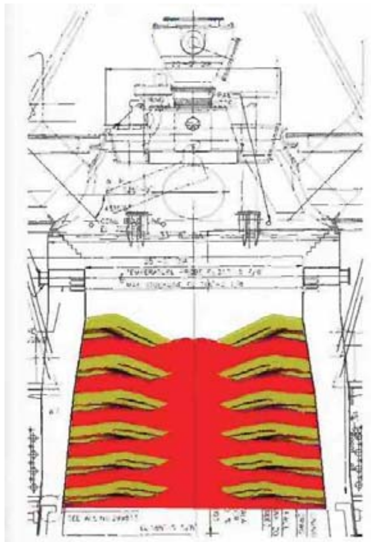
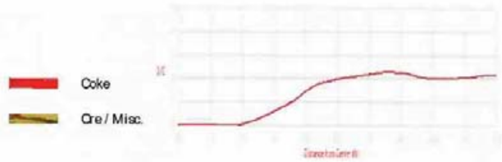


Fig.4 burden distribution comparison in different time on No.8 BF in USS Fairfield



Skip No.	Gate Pos	LH	Mat	Ring No. 1	2	3	4	5	6	7	8	9	10	11	Total
1			COKE												
2	4	1	COKE										2	8	10
3			COKE												
4	2	2	COKE	2	1	1	1	1	1	1					8
5			M1												
6	1	1	M2								1	2	3	4	10
7			M3												
8	1	2	O									2	3	5	10
9			O												
10			COKE												
11	4	1	COKE										2	8	10
12			COKE												
13	2	2	COKE	2	1	1	1	1	1	1					8
14			M4												
15	1	1	M5								1	2	3	4	10
16			M6												
17	1	2	O									2	3	5	10
18			O												



Proposed burden distribution change, corresponding to a coal injection rate of 230 lb/NTHM and a natural gas injection rate of 70 lb/NTHM. The table shows the number of revolutions of the chute at each ring.

Fig.5 the computer simulation model on No.1 BF in USSC Lake Erie Works

3. Top Video Camera

Thermal image camera using mechanical scanning method to get information from burden surface temperature distribution and monitoring video camera to observe BF

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internal situation were developed at the end of last century. Limited by the technical level at that time, problems such as the large device volume and big observation window opening on the furnace shell, complicated moving and protective mechanisms, short service life, complex focusing adjustment and high manufacture cost etc., became barriers for those techniques to be widely applied.

BF top video camera and image processing system were developed jointly by USTB and BSW. Several patents were authorized in China, Russia and USA [4,5,6,7]. Video camera mounted inside a stainless probe is inserted through the top of the furnace to take the internal images. It can be installed during a furnace stoppage. Water cooling and nitrogen purging are used to protect the camera and make it working steadily on line for long period under severe circumstance with high temperature, high pressure, high humidity and high density of dust. Ball valves and sealing rings are used to provide double sealing of the camera assembly, so it can be pulled out of the furnace and maintained easily without furnace stoppage. Thanks for the small view-window on this camera. It only consumes a little volume of nitrogen with very low cost during its service period.

Using BF top video camera, furnace operators in the control room can on line observe gas flow distribution images, the movements of charging chute or the big bell and burden stream inside the BF top. Some irregular phenomena such as channeling, slipping, chute trouble and spray failure can be monitored. With image processing system, quantitative data such as temperature distribution on the burden surface, temperature tendency and temperature pseudo-color diagrams can be obtained.

The first top video camera was installed at No.1 BF (bell less top, 380m3) at Shagang in December, 1999. Operators could see both central gas flow and edge gas flow on the burden surface clearly (see Fig.6). Besides, phenomena occurring during the furnace operation such as the movements of chute and stock line rod and burden distribution process were observed clearly. Irregular phenomena inside the furnace such as burden channeling and slipping can be detected. According to timely observation, operators could adjust burden charging to avoid unexpected furnace situation. For example, in October, 2000 a chute worn out was found by our top video camera system and maintenance was implemented at once. This camera has been used for some 12 years at No.1 BF and is still kept in a very good shape. An improved type of top video camera was installed at the 5800m^3 BF in Shagang, September 2009. It has been played a very good role for the BF smooth running.[6]

No.6 BF at Jinan Steel used image information obtained from the top video camera and image processing system to guide furnace restart operation. It helped the furnace reached its designed productivity in short time and long term steady running. Coke ratio was lowered at same time. #3 and #4 BF in Panzhihua Steel used our top video camera and image processing system have got very good result to guide BF production [8]. Fig. 7 is an image processing display interface which shows burden surface temperature distribution. Fig. 8 shows a top video camera installed on #4 BF, ArcelorMittal Dofasco Inc. Canada. An inner water leakage on the top water spray system was detected at #1 BF at USSC Lake Erie Works.

Nowadays, top video camera with image processing system has already become an indispensible tool for BF operators to obtain furnace internal information to guide operation and to avoid accident.

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Fig.6 Two gas streams in 380m3 BF at Shagang

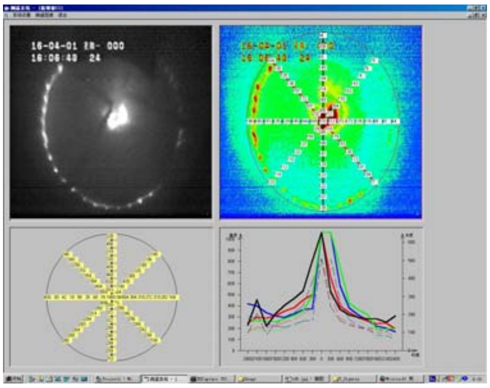

Fig. 7 Image processing interface

Fig.8 Top video camera at ArcelorMittal Dofasco

4. Thermal Camera

The current top video camera for furnace top observation obtains video images with CCD chip detecting near infrared light from burden surface. When the top temperature is higher say above 120℃, gas flow distribution image can be observed. Along with furnace size scaled up and operation level enhancement, top temperature is getting lower and lower. Black screen happens when the temperature is too low (under 120℃) because of the weak light signal. Near IR top video camera does not fully meet the requirement of modern BF.

Thermal camera is a kind of top temperature field monitoring device based on non-cooling IR Focus Plane Array (FPA) detector. It can detect far infrared radiation of the target within wave length of 7.5-13.5μm. Temperature distribution on the target surface can be reflected by IR radiation strengths at every spot. Based on this temperature distribution on project surface, thermal image and temperature distribution diagram are formed through signal transformation. This is the working regime for BF thermal camera. BF thermal camera has perfect cooling and other protective measures working under extreme severe circumstances in a BF, high temperature and high pressure, dusty and humid.

Figure 9 shows a thermal image at the top of Shagang 5800m^3 BF. Both top video camera and thermal camera are installed on this large modern BF[9]. Both video image and thermal image are displayed at same time on the two large screen monitors in control room. When top temperature is high, video image obtained from

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top video camera is clear. When top temperature is low, thermal image obtained from thermal camera is clear. Two cameras work together and help each other. It makes BF operators observe BF internal situation smoothly all the time.

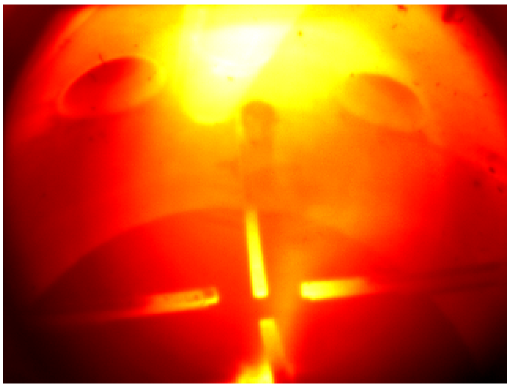

Fig.9 Thermal Camera Image of 5800m^3 BF in Shagang

5. Tuyere Camera

The new type of tuyere camera is amounted on the peep hole of BF tuyere. The camera has a light splitter which makes light is reflected into camera by mirror, see Fig. 10. Original peep holes can still be used for direct observing.
All the 40 tuyere on Shagang 5800m^3 BF are mounted with new tuyere cameras. Video signals are transferred into control room and all 40 tuyere working images are displayed on the monitor at same time, see Fig.11. Through watching tuyere images such as brightness in the front of each tuyere, coke movement and PCI stream etc. operators can understand the working status of each tuyere. Irregular phenomena can be found in time, for example cold slag skin and burden sliding [9,10].

A computer is used to process thermal images. Thermal conditions in the tuyere area such as temperature and PCI injected stream forms, can be analyzed quantitatively, see Fig. 12.[11] When irregular phenomena occur with troubles on burden falling movement or PCI, operators can use all the information to run the furnace correctly. Alarm system is activated whenever anything goes wrong with PCI operation or any unusual clue happening in front of the tuyere.

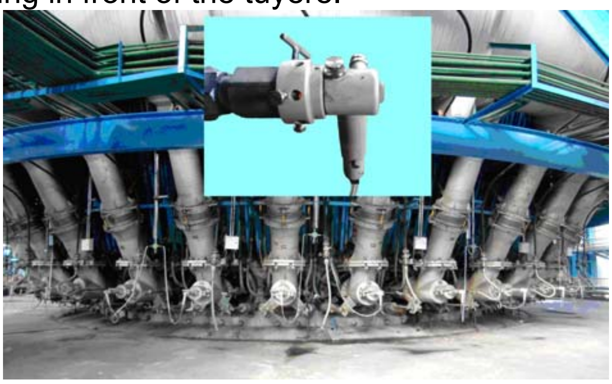

Fig10 Video camera installed on every tuyere

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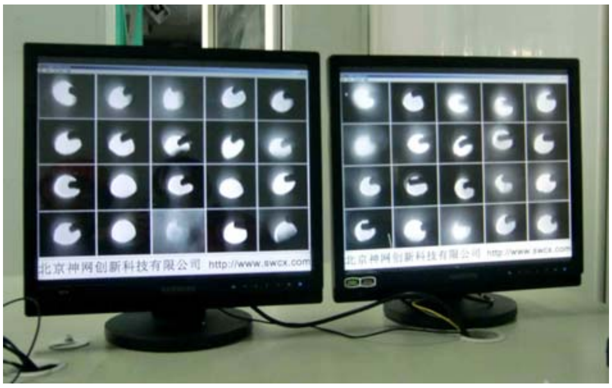

Fig.11 All 40 tuyere images in the control room

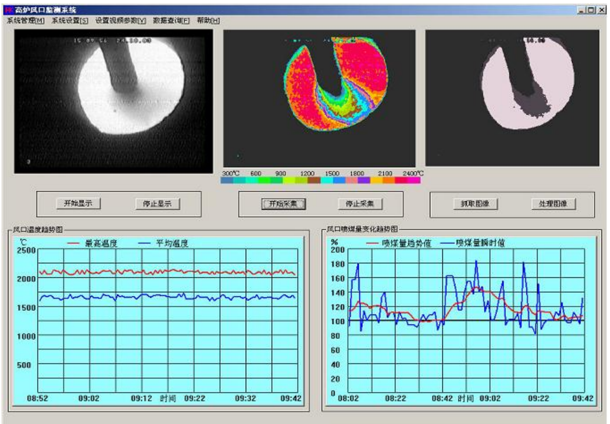
Fig.12 Computer interface for tuyere image processing

6. BF Laser Detector

Blast Furnace Laser Detector has been developed in order to observe burden surface profile during production. Two laser scanners are installed on the furnace top facing each other oppositely. A dedicated video camera is installed perpendicularly to the two laser scanners to get laser beam images. During BF running, video camera collects laser beam images scanning on the burden surface which is processed by a computer to obtain burden surface profile directly [12].

BF laser detector was firstly installed in a 1250m^3 furnace at Hangzhou Steel in October 2008. After 5 year trials and development, finally it becomes successful. #3 BF (1750m^3) at Jinan Iron & Steel Co. (JISCO) had 4 above burden probes originally. To avoid the blocking effect of these devices to burden distribution, three of them were taken out. In January 2012, two laser scanners and one video camera were installed on the flanges of the 3 original cross temperature devices. Two laser emitters generate laser beams on the burden surface with certain speed and the video camera takes laser images continuously. Clear burden surface profile was obtained with computer image acquisition and processing, see Fig.13.

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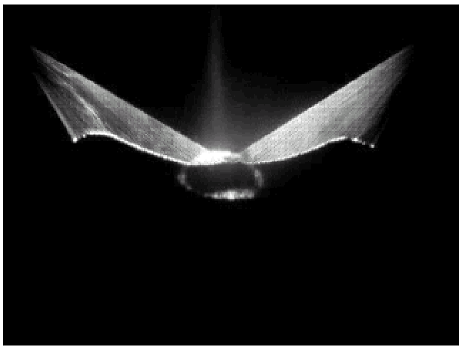

Fig.13 Laser image in 1750m3 BF at JISC

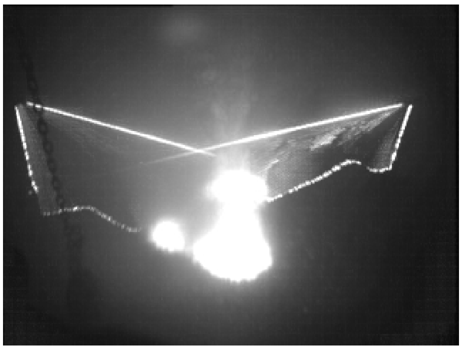

Fig.14 An burden slipping image in 2200m3 BF at Baotou

In March 2012, #1 BF (2200m^3) at Baotou I&S Co. installed a laser detector. A burden surface collapse was detected right after a burden slipping occurred (see Fig. 14). In April 2012, # 2 BF (2650m^3) at Shouqian Steel was installed with laser detector on 3 flanges of water spray holes. Very clears burden profile image was obtained during the furnace running, see Fig. 15.
Data and curves about burden surface profile can be obtained with computer processing on burden surface images, see Fig. 16.

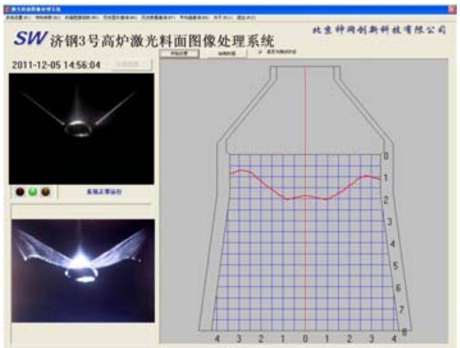

Fig.15 Burden surface image and computer processed profile

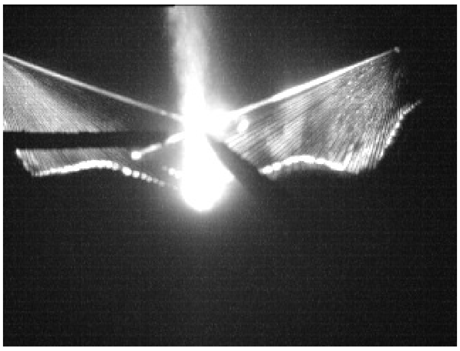

Fig.16 Laser image in 2650m3 BF at Shouqian Steel

Conclusions

BF visualization and simulation technologies assist operators understand burden distribution better. Simulation models are tools to guide burden charge operation and let operators well know equipment running status, burden surface profile and gas flow distribution, working status of each tuyere etc. Irregular phenomena inside the furnace and equipment troubles can be also detected immediately. Operators can use these

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facilities to run BF more smoothly and actively with steady production, long term service, higher gas utilization ratio and lower fuel ratio.
USTB and BSW developed jointly BF visualization and simulation technologies which are used widely at more than 450 BFs in mainland China and Taiwan CSC Group. Besides, more than 20 blast furnaces abroad are also using these technologies such U.S. Steel Gary works, U.S. Steel Kosice, Slovakia, U.S. Steel Canada Hamilton Works and Lake Erie Works, Magnitogorsk I & S Works Russia, ArcelorMittal Dofasco Inc. Canada, TATA Steel India, Kardemir and Edemir I & S Co. Turkey etc.

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