**Rough Set Based Analyzing Environmental Factors of On-line Monitoring of Smelting Alloy Steel by LIBS**

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**Abstract:** environment of metal smelting field is bad, measurement system of LIBS is easily affected by the environment factors. In this paper , the environmental impact factors of LIBS in iron and steel smelting process are analyzed comprehensively.Feature selection of rough set theory is combined to deal with the gathered data from the literature. The analysis from the literature shows that it is identical that temperature and atmosphere have much influence on the spectral line

**Key Words:** LIBS,Rough set,Influence factors of the environment,Metal smelting

[[1]](#footnote-0)

1. Introduction

LIBS is an atomic emission spectroscopy technique which uses highly energetic laser pulses to provoke optical sample excitation [1]. The interaction between focused laser pulses and the sample creates plasma composed of ionized matter. Plasma light emissions can provide“spectral signatures” of chemical composition of many different kinds of materials in solid, liquid, or gas state. LIBS can provide an easy, fast, and in situ chemical analysis with a reasonable precision,detection limits, and cost. Additionally, as there is no need for sample preparation, it could be considered as a “put & play” technique suitable for a wide range of applications. An in-situ analysis of steel requires a fast, non-contact and reliable method with no need for any sample preparation, and that can be carried out under various atmospheric conditions. Laser Induced Breakdown Spectroscopy LIBS meets these demands .so it becomes a hot point in the research that online analysis of dissolved metals bases on the LIBS technique. Yao Shun chun et al.[3]designed a set of LIBS the experimental system of measuring the on-line elemental composition of a molten alloy inside the melt in a furnace for studying liquid steel surface oxidation by air .Sun lan xiang[8] in their laboratory room uses LIBS [technology](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) to on-line monitoring Cr, Si, and Mn element mass fraction. The studying result showed that the liquid steel temperature strong affected plasma emission intensity, and the spectral line's intensity of different elements varies in terms of temperature.elements varies in terms of  temperature.Chen kai et al. [4] in their work applied LIBS to monitoring elemental composition of molten steel,and Results show that argon gas,also as protection gas,not only avoid the argongas,also as protection

gas,not only avoid the oxidation on the surface of moltensteel,but also enhance the signal intensity of plasma . In this work the key environment factors will be filtered from multitudinous [environmental](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) attribution in Iron and steel smelting process using rough set [indistinguishable](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) relation method .

Rough set theory,proposed by Pawlak during 1980s,deals

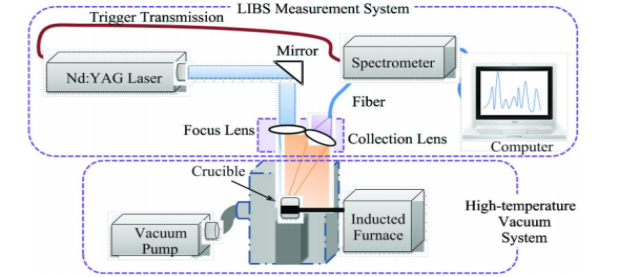
with uncertainty, vagueness, imprecision, and incomplete

information [5]for feature selection, feature reduction, and extraction of decision rule from the given data set. [indistinguishable](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) relation method of rough set theory is used to select minimal representative subset of the attributes from the data set

This paper begins with a brief explanation of principles of LIBS measurement and high frequency induction and describes LIBS system influence factors including the following three aspects: LIBS Set-Up Components ; Metal smelting environment; Spectral data collection and analysis. Especially in the aspect of molten alloy working environment, a detailed environmental influence is analyzed. Rough set theory and the feature extraction method is then followed. Finally, feature selection of rough set theory is combined to deal with the gathered data from the literature. The analysis from the literature shows that it is identical that temperature and atmosphere have much influence on the spectral line.Instructions for Authors

**2 Analysis of influencing factors of LIBS on line detection technology**

LIBS System is shown schematically in Figure.1 ,which include LIBS Measurement System and High-temperature Vacuum System. LIBS Measurement System comprises a laser light source,laser focusing lens, optical lens, optical signal acquisition and spectrum, and spectrometer; high temperature vacuum system includes induction furnace, vacuum chamber, vacuum pump and vacuum gauge, which used to provide a vacuum environment and sample heating.

 Figure.1 LIBS System

Firstly , Laser emitted by a ND:YAG Laser is reflected by the reflecting mirror and then is focus on the surface the sample by the lens focus,which produce a laser plasma consisted by high temperature and high density and free electrons, ions and atoms .The formation of laser induced plasma will expand with decreasing temperature continues, at his point the particle in the excited states will transit to the ground or low energy level and emit a particular frequency spectra. The spectral data is formed by the plasma spectral signal which collected by the spectrometer[9]. According to the specific wavelength of the spectrum, it can be determined that the spectrum belongs to which element and then make sure the elements in the sample to be tested. From the above can be known, the whole measurement system is easily affected by the environment factors, and environment of metal smelting field is bad, the optical path system and the detection instrument will have an impact on the spectral intensity .influence factor of LIBS is shown in table 1,

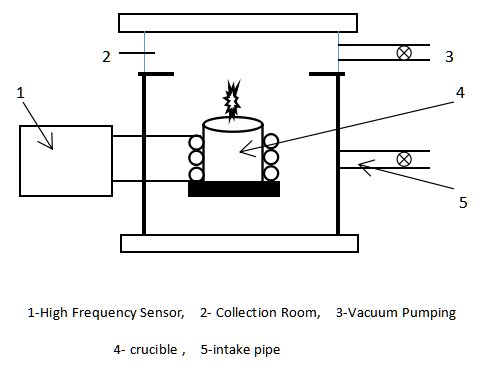


Figure.2 Experimental Device For High Frequency Induction Furnace

Table 1:Influencing Factors Of LIBS System

**LIBS Set-Up Components Data analysis link**

Pulsed laser Spectrometer and optical path

Single or double pulse laser Spectrometer and data average of multiple measurements

Energy Lens focusing Extraction and amplification of weak signals

Wavelength and pulse width Detection angle deal with Self-absorption effect

Frequency Time delay device Matrix effect

probe

which include LIBS Set-Up Components and Spectral data collection and analysis.Experimental device for high frequency induction furnace is shown in Figure.2. Which is a device that converts electric energy into heat energy by using electromagnetic induction principle. The principle is when the conductor curled into ring connect to high frequency AC power supply , it will generate a large magnetic induction intensity of the alternating magnetic field . And the middle of the ring will produce magnetic beam. the metal body in ring can produce eddy current and emit Joule heat to melt metals.In the practice of industrial production, liquid steel production equipment, such as steel converter or vacuum treatment equipment connected with the measurement equipment is very bad environment ,so 9 environmental impact factors is analyzed in Table 2.

Table 2: Environmental Impact Factors

**influence factors of environment**   **[description](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);)**

Temperature Due to temperature changes can cause nonlinear distortion of the spectrum in optical signal

(The outside and inside of the furnace) transmission system,detector and signal conversion and transmission devices

chen Jinzhong et al.[10] study the Radiation characteristics in their Paper,the result show that

electromagnetic radiation that The radiation intensity of the plasma is enhanced with the increase of the magnetic field

field intensity

Electromagnetic stirring The flow velocity and direction of molten iron will affect the accuracy and real-time of the

measurement.

Vibration Influence on the focusing of the lens and The accuracy of the measurement

Evaporation effect between alloys The presence of the medium can cause reflection,Refraction and attenuation of light.

Type of gas Under different atmosphere conditions (argon, nitrogen or oxygen etc), the measured signal

is affected by the influence of the masking effect etc

pressure Gas pressure will influence plasma expansion.Low pressures increase energy losses and

uniformity of the plasma energy distribution

Distance of laser to liquid no

3  Rough set theory and the feature extraction

method

Information System Table. Information system table is a two dimensional table (column and row). The row shows definite number of objects, whereas the column shows the attribute value and class label of the objects [6]. It can be presented as where is finite set of objects,is set of attribute, andis decision.

Indistinguishable RelationIt is an equivalence relation ,indistinguishable relation is defined as： .usually also called 

Upper approximation of a setincludes all objects of information system table which possibly belongs to the class. Lower approximation of setis the set of objects of the information system table which certainly belongstothe class.Te set of all objects that belong to lower approximation is referred to as positive region.The difference between upper approximation set and lower approximation set is referred to as boundary region. Equations show mathematical formula for (,,,)







Dependency of attributes. we can measure dependence on each other betweenandwith rough membership function,which is defined as:



In the above equation, card（· ）represents the cardinal of the set.

Redundant attribution. Forandsubset of attributes letif is true,is redundant in thesubset of attributes,otherwiseis indispensable in thesubset of attributes

3.1 the feature extraction of basic ideas

According to the attribute dependency of thought, when processing [feature](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) [extraction](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);),is calculated in the decision system table which is [degree](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) [of](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) [dependence](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) of [decision](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) [attributes](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) relative to each condition attribute set  in condition attributes. Because of card（· ）fixed in the same,The value ofis determined by. We only need calculate Positive region ofand then sort according to the size of them.Meanwhile, in order to ensure that classification ability of the selected feature setnot changed relative to [decision](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) [attributes](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);), positive region could be calculated preferentially. So when processing feature [extraction](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);),(is environmental impact factors of metal smelting and represents decision attributes ) is computed and determine whether it is equal to 

**2.3 Algorithm description**

1. decision information system table ；
2. calculating ;
3. calculating positive region ofand then sort according to the size of them .the result of sorting called and the size of the positive domain of each attribute is also required.
4. let={ };
5. Select the attribute of the current maximum positive domain from  if   go to (7); else Go to(6);
6. if exist,C` and  if exit one or many calculate  and chooseof the maximum   ,; go to (5); else , go to (5);
7. Output 

**3 Data processing and result analysis**

*Data collection*. For this study data sets have been selected from previous literature . Principles collected by data are follows: 1,parameters of LIBS system possibly is same; 2, data collected possibly is from  identical experiment. Based on the above two principles , six environmental factors of LIBS are selected ,which are distance form sample to focus, pressure, type of gas,electromagnetic radiation, temperature and angle of incidence. The energy parameters related with laser material interaction are influence and irradiance (energy per unit area and time,W/cm2). The effect of changes in the laser energy is related to laser wavelength and pulse time. Difference of physical characteristics of the material itself and elements selected will cause the difference in concentration. energy parameters, physical characteristics and type of elements are chosen . So a decision table is constructed by 25 samples with 9 conditional attributes and a decision attribute(Spectral intensity as decision attribute) . There are missing values in decision table. A show of the decision table is given in Table 3.

*Handling Missing Value*. Handling of missing values is a data preprocessing technique to obtain a smooth data set. Te common methods include ignoring the tuple that holds missing value, imputing with the mean, or imputing with the most frequent value [7] In this study, missing value is handled as follows. If the percentage of missing value in a tuple is greater than or equal to 25%, then reject that tuple from the data set or else impute it by the most frequent value of the attribute in the class that belongs to the tuple. Te same applies to attributes too.

|  |
| --- |
|  |

Figure.3 Flow Diagram Algorith

Table 3: Environmental Influencing Factors Of LIBS As A Decision Table

No.   [energy](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) distance form physical pressure type electromagnetic angle temperature type of Spectral

to focus characteristics of gas radiation elements intensity

/mm /MPa /T /℃

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | 0.2 | 0 | soil | 0.1 | air | 无 | vertical |  | Al | 11 |
| 2 | 0.2 | 0 | soil | 0.1 | air | 0.3 | vertical | [normal](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) | Al | 13 |
| 3 | 0.2 | 0 | soil | 0.1 | air | 0.5 | vertical | [normal](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) | Al | 17 |
| 4 | 0.2 | 0 | soil | 0.1 | air | no | vertical | [normal](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) | Fe | 10 |
| 5 | 0.2 | 0 | soil | 0.1 | air | 0.3 | vertical | [normal](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) | Fe | 14 |
| 6 | 0.2 | 0 | soil | 0.1 | air | 0.5 | vertical | [normal](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) | Fe | 15 |
| 7 | 10 | 0 | metal | 0.5 | Ar | no | vertical | [normal](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) | Cu | 900- 950 |
| 8 | 0.2 | 0 | soil | 0.1 | Ar | no | vertical | [normal](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) | Al | 16- 18 |
| 9 | 6 | 0 | metal | 0.1 | air | no | vertical | [normal](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) | Mn | 80- 100 |
| 10 | 6 | 0 | metal | 0.1 | air | no | vertical | [normal](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) | Fe | 70- 80 |
| 11 | 6 | 0 | metal | 0.1 | N2 | no | vertical | [normal](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) | Fe | 80- 100 |
| 12 | 6 | 0 | metal | 0.1 | N2 | no | vertical | [normal](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) | Mn | 100- 120 |
| 13 | 6 | 0 | metal | 0.1 | Ar | no | vertical | [normal](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) | Fe | 300- 320 |
| 14 | 6 | 0 | soil | 0.6 | Ar | no | vertical | [normal](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) | Si | 550- 600 |
| 15 | 6 | 0 | soil | 0.6 | Ar | no | vertical | [normal](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) | Fe | 400- 450 |
| 16 |  | 0 | soil | 0.8 | Ar | no | vertical | [normal](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) | Cu | 970- 1050 |
| 17 | 0.2 | 6 | soil | 0.1 | air | no | vertical | 200 | Fe | 23 |
| 18 | 0.2 | 6 | soil | 0.1 | air | no | vertical | 200 | Al | 16 |
| 19 | 0.2 | 6 | soil | 0.1 | air | no | vertical | 200 | Mg | 19- 20 |
| 20 | 0.2 | 6 | soil | 0.1 | air | no | vertical | 250 | Fe | 25 |
| 21 | 0.2 | 6 | soil | 0.1 | air | no | vertical | 250 | Al | 17- 18 |
| 22 | 0.2 | 6 | soil | 0.1 | air | no | vertical | 250 | Mg | 21- 22 |
| 23 | 0.2 | 6 | soil | 0.1 | air | no | vertical | 300 | Fe | 25- 26 |
| 24 | 0.2 | 6 | soil | 0.1 | air | no | vertical | 300 | Al | 19 |
| 25 | 0.2 | 6 | soil | 0.1 | air | no | vertical | 300 | Mg | 23- 24 |

|  |
| --- |
| [energy](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);)： 6J-10J(including terminal): 1;200mj: 2  distance form  focus to sample 0: 1;6mm: 2  physical  characteristics： soil: 1;metal: 2  pressure： 0.1: 1;0.5MPa-0.8MPa(including terminal): 2  electromagnetic  radiation： no: 1; 0.3T: 2;0.5T: 3  type of gas： air: 1;Ar: 2;N2: 3  angle： vertical: 1  temperature： [normal](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);): 1;200: 2; 250: 3;300: 4  type of elements： AL: 1;Fe: 2;Cu: 3;Mn: 4;Mg: 5  spectral intensity：0-20: 1; 20-50: 2;50-500: 3;500-1500; 4 |

*discretization of data.* Since the Pawlak’s rough set model is more suitable for data containing discrete attributes, continuous attributes should be discretized as a preprocessing step in rough sets ,in the Table1,Attribute values of 2,3,5,7,11 column are nonuniform distribution but are gathered in intervals,continuous attributes are discretized by close together between attribute values. concrete operation is followed as Table 4 .And Table 5 shows decision table of discretized, where a,b,c,d,e,f,g,h and i respectively indicate [energy](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);), distance form to focus ,physical characteristics ,pressure ,type of gas ,electromagnetic radiation, angle ,temperature, type of elements, spectral intensity. D is spectral intensity.

*reduction and Result analysis.* Attribute reduction in rough set theory is also called feature selection; it aims to remove unnecessary attributes while retaining the discernibility of objects under the original attributes. In this paper, algorithm of blind attribute reduction is applied , A program about algorithm is programmed in vs2010. Flow diagram of algorithm is given in Figure.3 .reduction result is shown in Table 6

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| N. | a | b | c | d | e | f | g | h | i | D |
| 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 |
| 3 | 2 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 |
| 4 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 |
| 5 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 1 |
| 6 | 2 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 2 | 1 |
| 7 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 3 | 4 |
| 8 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 |
| 9 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 4 | 3 |
| 10 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 3 |
| 11 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 2 | 3 |
| 12 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 4 | 3 |
| 13 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 3 |
| 14 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 4 | 3 |
| 15 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 2 | 3 |
| 16 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 3 | 4 |
| 17 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 |
| 18 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 |
| 19 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 5 | 1 |
| 20 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 3 | 2 | 2 |
| 21 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 1 |
| 22 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 3 | 5 | 2 |
| 23 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 4 | 2 | 2 |
| 24 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 4 | 1 | 1 |
| 25 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 4 | 5 | 2 |

Table 5: Discretized Decision Tables

Table 4: Principle Of Discretization

Table 6: Table Of Reduction Result

information system Result of attribute reduction

physical characteristics

The main factors affecting type of gas

the spectral intensity temperature

type of elements

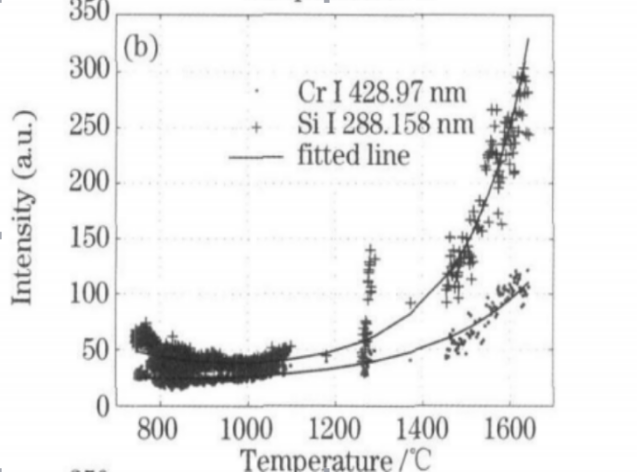


Figure4

In the table 5,Angle,electromagnetic radiation,distance form focus to sample,[energy](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);),pressure are unnecessary attributes but physical characteristics, type of elements, temperature,type of gas are retained as the key environment factors. Given the physical characteristics and the type of elements not belong to environment factors of LIBS, Final results are type of gas and temperature. Sun lanxiang[8]in their laboratory room uses LIBS [technology](D:/youdao/Dict/6.3.69.8341/resultui/frame/javascript:void(0);) to on-line monitoring Cr, Si, and Mn element mass fraction. The studying result showed that the liquid steel temperature strong affected plasma emission intensity,and the spectral line's intensity of different elements varies in terms of temperature,which is consistent with the temperature as a necessary attribute. Figure 4 shows the relationship between temperature and intensity in literature[9], On the other hand, Under different atmosphere conditions (argon, nitrogen or oxygen etc), the measured signal is affected by the influence of the masking effect etc.

4 Conclusions

This paper begins with a brief explanation of principles of LIBS measurement and high frequency Induction and describes LIBS system influence factors . Especially in the aspect of molten alloy working environment, a detailed environmental influence is analyzed. Rough set theory and the feature extraction method is then followed. Finally, feature selection of rough set theory is combined to deal with the gathered data from the literature. The analysis from the literature [8]shows that it is identical that temperature and atmosphere have much influence on the spectral line. So we can get some advice from this conclusion for the quantitative analysis of steel smelting with LIBS.In terms of LIBS metal detection , The method of rough set has not been used in known literature to do a comprehensive analysis of the interference of environmental factors.

References

1. B. Kearton and Y. Mattley, “Laser-induced breakdown spectroscopy: sparking new applications,”Nature Photonics, vol. 2, no.9, pp. 537–540, 2008.
2. D. A. Cremers, L. J. Radziemski, and J. Wiley, Handbook of Laser-Induced Breakdown Spectroscopy,John Wiley & Sons, 2006.
3. Yao shun chun ，Lu ji dong， Li jun yan et． Effect of air oxidation on the direct measurement of liquid steel composition [J].Journal
4. of South China University of Technology: Natural Science Edition ，2011，39( 1) : 63- 67
5. Chen kai ，Lu ji dong， Li jun yan． Real time quantitative analysis of multi elements in liquid steel by LIBS [J]．Spectroscopy and Spectral Analysis，2011，31( 3) : 823-826．
6. Z. Pawlak and A. Skowron, “Rudiments of rough sets,” Information Sciences, vol. 177, no. 1, pp. 3–27, 2007
7. Z. Pawlak, “Rough sets,” International Journal of Computer and Information Sciences, vol. 11, no.5, pp. 341–356, 1982.
8. Z. Pawlak and A. Skowron, “Rudiments of rough sets,” Information Sciences, vol. 177,no. 1, pp.3–27, 2007
9. Sun Lanxiang, Yu Haibin, Xin Yong et al. On line monitoring of liquid steel composition based on laser induced breakdown
10. spectroscopy ［ J］．China laser， 2011, 38 ( 9 ) : 0915002
11. Wenfeng Luo, The Study of Laser-Induced Breakdown Spectroscopy.State Key Laboratory Of Transient Optics and Photonics Xi’ an
12. Institute of Optics and Precision Mechanics Chinese Academy of Sciences .2011
13. [10]Chen Jinzhong, Bai Jingning, Wang Jing, sun Jiang, Guo Shuqing magnetic confinement technology on laser induced plasma radiation Effect of characteristics[J] .IGH POWER LASER AND PARTICLE BEAMS 2014,26(1):0212002

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