

## Data Mining on production strategies of Indian Bauxites

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### Article Info

#### Article history:

Received Agu 09, 2014

Accepted Sep 12, 2014

Available online Mar 02, 2015

#### Keywords:

Data Mining,

Bauxite,

Refractory,

Metallurgical,

Response surface methodology,

Export,

Import,

Internal consumption.

### Abstract

The present paper deals with the retrieval of the data from the mineral year books of Indian Bureau of Mines and Government of India web sites with particular reference to the production strategies of Indian bauxites and its analysis for dictating the India's future out look. The data reveal that Indian refractory grade bauxite is very limited and it is mostly restricted in Gujarat state where as the metallurgical grade bauxite is abundant but mostly consumed in house industries with limited exports. In view of this, on the basis of data mining information it is recommended to Government R & D organizations and public sectors to take up innovative research on beneficiation or up gradation of low grade bauxites as well as alumina bearing weathered khondalite rocks suitable for different industrial applications.

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## 1. Introduction

Data mining is the process of analyzing data from different perspectives and summarizing it into useful information. Data are any facts, numbers, or text that can be process by a computer. The patterns, associations, or relationships among all collected data can provide information. Information can be converted into knowledge about historical patterns and future trends. To maximize user access and analysis, there needs to be a centralization of data in a data warehouse [1]. Bauxite is basically an aluminous rock containing hydrated aluminum oxide as the main constituent and iron oxide, silica and titania in varying proportions. Bauxite is an essential ore of aluminum which is one of the most important non-ferrous metals used in the modern industry. It is also an essential ore for refractory and chemical industries. The country has abundant resources of bauxite which can meet both domestic and export demands but the refractory grade bauxite is very much limited. The Indian Bureau of Mines, The Government of India, has published a series of Mineral Year Books. In the present paper an attempt is made to retrieve the data or mined out the data from the Mineral year books of Indian Bureau of Mines with particular reference to the production strategies of Indian bauxites [2-3].

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## 2. Resources

The world bauxite reserve base is estimated at 38,000 million tons, located mainly in Guinea (23%), Australia (21%), Vietnam (14%), Brazil and Jamaica (7% each), China (6%) and India (4%). Resources of bauxite in the Indian country as on 1.4.2005, as per UNFC system, are placed at 3,290 million tons. These resources include 899 million tons reserves and 2,390 million tons remaining resources. By grades, about 86% resources are of metallurgical grade. The resources of refractory and chemical grades are limited and together account for about 3%. By States, Odisha alone accounts for 55% of country's resources of bauxite followed by Andhra Pradesh (19%), Gujarat (6%), Chhattisgarh (5%), Madhya Pradesh (4%), Jharkhand (4%) and Maharashtra (3%). Major bauxite resources are concentrated in the East Coast bauxite deposits in Odisha and Andhra Pradesh. The details of these Indian resources state wise and grade wise are given in Tables 1 and 2 respectively.

**Table 1.** Indian bauxite reserves [state wise]

State	Proved Reserves, Tons, 000
Andhra Pradesh	199
Bihar	-
Chhattisgarh	30706
Goa	27037
Gujarat [refractory grade]	43952
Jammu & Kashmir	-
Jharkhand	13408
Karnataka	4576
Kerala	55
Madhya Pradesh	13530
Maharashtra	21091
Orissa [metallurgical grade]	380363
Rajasthan	-
Tamil Nadu	4029
Uttar Pradesh	-
Total	538945

**Table 2.** Indian bauxite reserves [grade wise]

Grade	Proved Reserves, Tons, 000
Chemical	680
Refractory	3370
Chemical/refractory, mixed with others	2579
Metallurgical-1	426501
Metallurgical-2	51247
Metallurgical, mixed	11363
Low	23538
Mixed grade excluding chemical/refractory	15327
Abrasive	194
Others	191
Unclassified	3515
Not-known	441
Total	538945

### 3. Data Mining

#### 3.1. Production strategies

In The production of all grades of Bauxite of India during years 2000 to 2012 and the production in particular from 2007 to 2012 from different states of India are shown in Fig 1 and Fig 2. The data shown in Fig 1 is on production of all grades of bauxite during the year 2000-2012 indicate that the production of bauxite is 700000t during 2000-2001 and it has been continuously increasing from 2001-2007 (1500000t) and the demand for production of bauxite during 2007-2008 is significantly maximum 23000000t and subsequently the production of bauxite decreased from the year 2008-2012, specially during 2011-12 the production of bauxite is decreased to 1300000t. The data on production of bauxite from different states of India particularly during 2007-2012 are given in Table 3 and shown graphically in Fig 2 indicate that the production of bauxite is negligible from the states of Goa, Karnataka and Tamil Nadu compare to other producing states. The production trend is almost similar for the states of Chhattisgarh, Jharkhand and Maharashtra. The production of bauxite from Madhya Pradesh is relatively lower from the previous mentioned states.

**Table 3.** Bauxite production and value from different states during 2007 -12

States in India	2007-08		2008-09		2009-10		2010-11		2011-12	
	Production, Tons	Value, Rs.	Production, Tons	Value, Rs.	Production, Tons	Value, Rs.	Production, Tons	Value, Rs.	Production, Tons	Value, Rs.
CHHATTISGARH	1793819	708262	1674427	557371	1687069	607911	2109949	777273	2365304	1268221
GOA	129259	9694	463150	34736	31050	3105	100900	10090	84700	8470
GUJARAT	11922675	2272525	3514016	897680	2687306	667424	938574	570664	843497	430400
JHARKHAND	1249605	406395	1585356	552684	1670577	673016	1855993	627327	1830850	692085
KARNATAKA	161529	31875	127830	24418	123316	32748	64643	11348	83019	20157
MADHYA PRADESH	533664	158624	1037724	376581	1056847	365097	616319	262437	617146	205571
MAHARASHTRA	1805366	565635	2053512	625275	1985006	628556	2133736	549201	1937898	505268
ORISSA	4685998	1486174	4734421	1591786	4879580	1909188	4856808	2305022	5045888	2372555
TAMIL NADU	343045	44682	269766	42690	3342	852	45898	8789	69092	17305
INDIA [TOTAL]	22624960	5683866	15460202	4703221	14124093	4887897	12722820	5122151	12877394	5520032

However interestingly it can be seen and noted the production trend of bauxite specially refractory grade bauxite from Gujarat is significantly very high during the year 2008 and the production trend of bauxite gradually decreased by the end of the year 2012. Whereas the production of metallurgical grade bauxite from the state of Odisha is less than 20 % during the year 2008 and it has gradually increased the production of metallurgical grade bauxite in the year 2012 (greater than 40% production). The variation in the mining of bauxite for the production of refractory to metallurgical grade bauxite from the year 2008- 2012 is probably due to non- availability of required grade of refractory bauxite are mining of alternate raw materials for refractory applications and the trend in demand of metallurgical application of bauxite for Indian industries.

The production for metallurgical and refractory grade bauxite from different states of India especially during the year 2007-08 and 2011-12 are shown in the Fig 3 and Fig 4. It can be seen from Fig 3 that the production of bauxite from the Gujarat state which contain the refractory grade bauxite is maximum, compare to the other states of India. It can also be seen that next to Gujarat state the production of bauxite from Odisha state which is metallurgical grade bauxite is maximum in the states of India. According the values obtained from the production of bauxite varies mainly depend on the number of tons of bauxite mined out for industrial applications or commercial purpose.

The recent trend in the production of bauxite and the value obtained from the production in different states of India during 2011-12 shown in Fig. 4 indicates that the production of metallurgical grade bauxite from the Odisha state is significant compare to the production of refractory grade bauxite from Gujarat state as seen contradictory from the earlier Fig 3. The data shown in Fig 1a and 1b on production of bauxite from different states of India indicate that the demand for production and consumption of refractory grade is maximum during the year 2007-08, where as the demand for production and consumption of metallurgical grade bauxite is maximum during the year 2011-12.

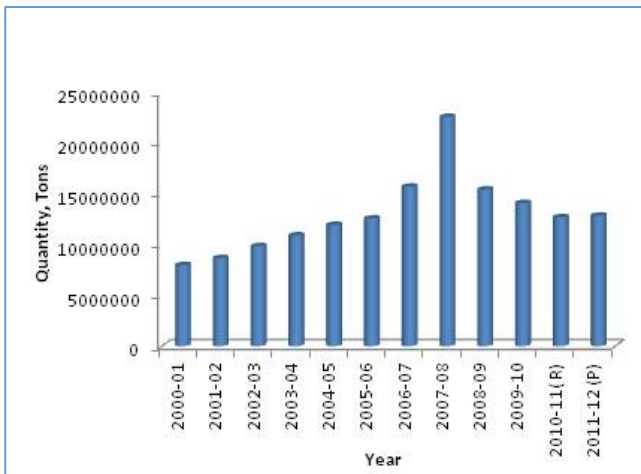


Fig 1. Production of all grades of Indian Bauxite

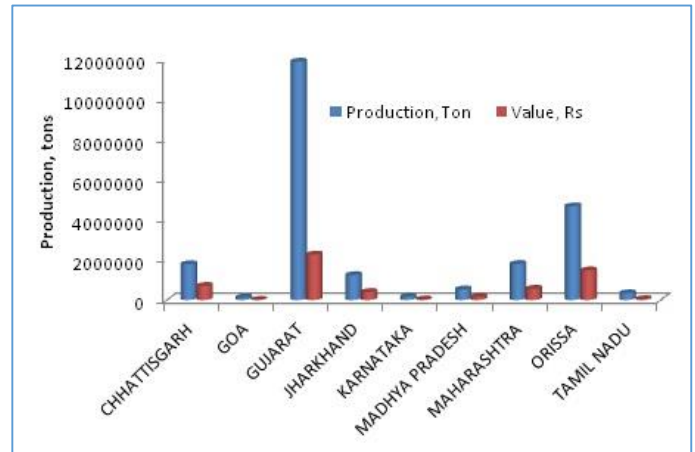


Fig 3. Bauxite production and value from different states during 2007 -08

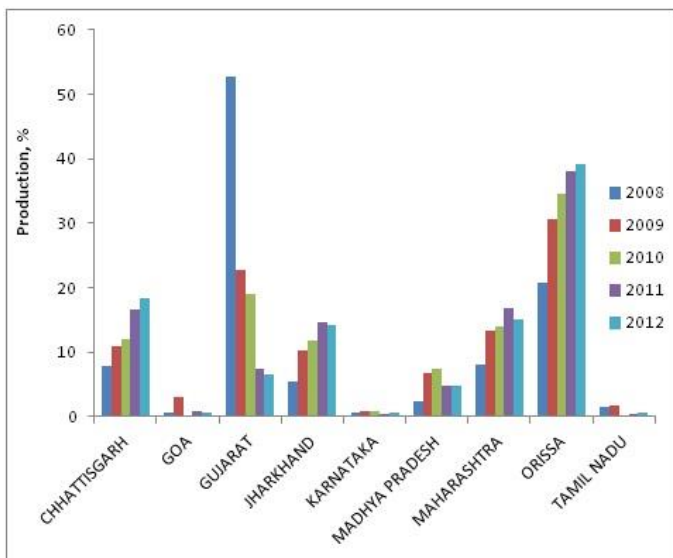


Fig 2. Production of Bauxite in different states of India during 2007-2012

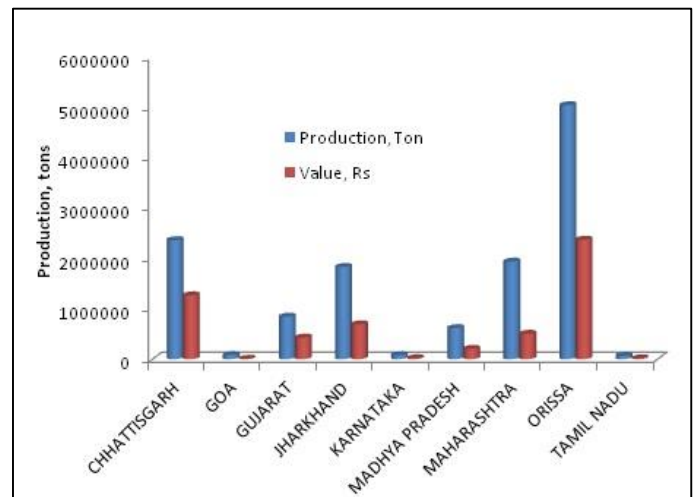


Fig 4. Bauxite production and value from different states during 2011 -12

The production of bauxite both metallurgical and refractory grade and its value in percent are shown graphically in Figs. 5 and 6. It is a fact that based on the geological information the states of Odisha and Andhra Pradesh possess the metallurgical grade bauxite and the western India specially the state of Gujarat possess only the refractory grade bauxite. It may be recalled again that the Gujarat state is posing and refractory grade bauxite. However, the grade of bauxite may vary from low to medium and to high grade bauxite suitable after beneficiation of blending the different grades of bauxite for refractory applications. The production trend and its value can be seen from Fig. 5. The data shown in Fig. 5 indicate that the mining and the production of refractory grade bauxite is significantly higher during 2007 to 2008 and gradually the production of refractory grade bauxite has fallen to as low as to 5% from the year 2007 to 2012. As expected the value obtained from the production has also fallen down from year 2007 to 2012.

The production of metallurgical grade bauxite and the values obtained due to production from the state of Odisha during the year 2007 to 2012 is shown in Fig 6. The data indicate that the production of metallurgical grade bauxite from year 2007 to 2012 is gradually increasing due to the requirement of Indian Industries. As expected the values obtained from the production are also increases due to constant increase in production of bauxite during the year 2007 to 2012.

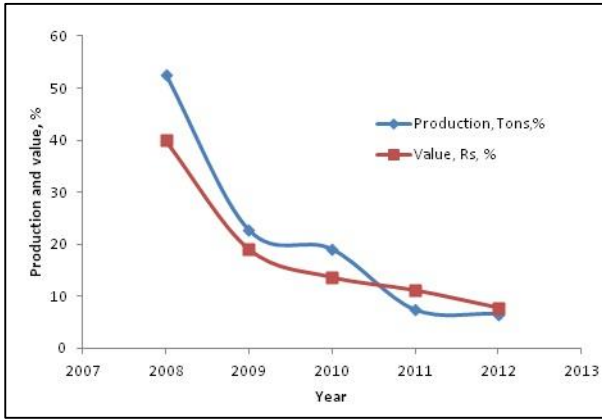


Fig 5. Refractory grade Bauxite production trend in Gujarat state

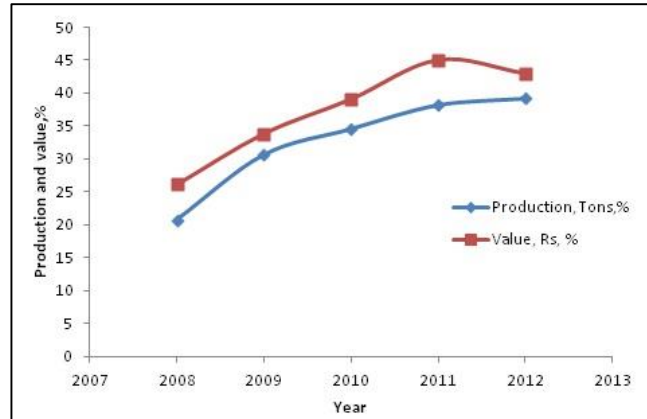


Fig 6. Metallurgical grade bauxite production trend in Odisha state

**3.2. Exports and imports strategies**

The production, exports, imports of Indian bauxite and its internal consumption are given in Tables 4 and 5 and Figs. 7 -9. The data shown in Fig.7 indicate the export of all grades of bauxite of India. It is observed from the Fig.7 that the export of bauxite, during year 2001-02 is below 1,000,000t of bauxite and the export of bauxite is in turmoil during 2002-06 and the gradually the export of bauxite has been enhanced due to high production of bauxite as well as the demand in foreign countries. During the year 2006-07 the export value of bauxite is around Rs.50, 000,000t and 2007-08 it is around Rs. 70,000,000t which is maximum beyond this period, the export has significantly fallen down. This may be due to the demand of Indian metallurgical industry.

**Table 4.** Bauxite production, export, import and internal consumption during 2003 -12

Year	Production, Tons	Export, Tons	Internal consumption, Tons	Import, Tons	Export, %	Internal consumption, %
2003	9867455	1785352	8082103	44183	18.1	81.9
2004	10924786	896138	10028648	37432	8.2	91.8
2005	11964011	1016141	10947870	56398	8.5	91.5
2006	12595803	2355277	10240526	45240	18.7	81.3
2007	15732535	5073894	10658641	47138	32.3	67.7
2008	22624960	7120899	15504061	122911	31.5	68.5
2009	15460202	1708349	13751853	45612	11.0	89.0
2010	14124093	475692	13648401	54345	3.4	96.6
2011	12722820	116066	12606754	63584	0.9	99.1
2012	12877394	401027	12476367	7898	3.1	96.9

**Table 5.** Reported Consumption of Bauxite in India<sup>†\*</sup>, 2006-07 to 2008-09 (By Industries)

Industry	2006-07 (R) in tons	Industries, units	2007-08 (R) in tons	Industries	2008 -09(p) in tons	Industries, units
Abrasives	4200	5	4200	5	4200	5
Alumina <sup>1/</sup>	9304600	4	9652500	4	9559300	4
Cement	693400	24	614900	24	1053200	27
Ceramic	100	3	100	3	100	3
Chemical	6800	3	6500	3	5900	3
Ferro-alloys	7600	3	13600	4	13600	4
Fertilizer	18200	2	18200	2	18200	2
Iron & steel	1200	7	1200	7	1200	7
Refractory <sup>2/</sup>	280300	56	288700	59	287000	59
Total	10316400	107	10599900	111	10942700	114

<sup>†</sup> \*Excludes industrial end - use consumption of laterite which was 2,183.300 tons, 2.231.100 tons and 2,817,600 tons during 2006-07, 2007-08 and 2008-09, respectively.

1. Includes about 6,726 thousand tons, 8,708 thousand tons and 8,594 thousand tons bauxite equivalent of alumina estimated to have been consumed in the production of aluminum metal in 2006 - 07, 2007-08 and 2008-09, respectively.
2. Includes consumption of calcined bauxite.

The import of all grades of Indian bauxite, during 2002 to 2012 shown in Fig.8 indicates that the average trend for import of bauxite during 2002 to 2012 is almost similar except during the year 2007-08. During this period India has seen the demand for production as well as import of refractory grade bauxite. Hence, the import of bauxite and the production of refractory grade bauxite are maximum.

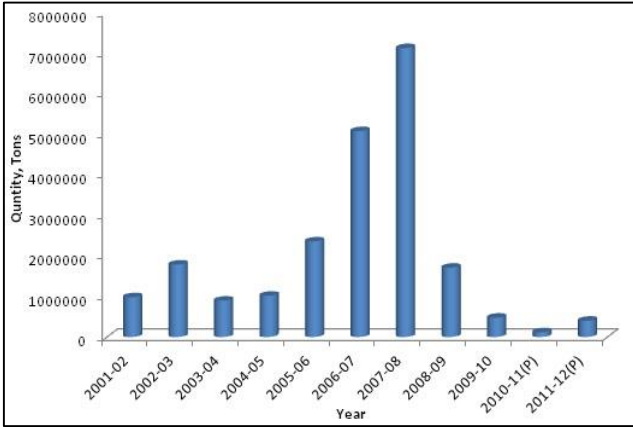


Fig 7. Export of all grades of bauxite

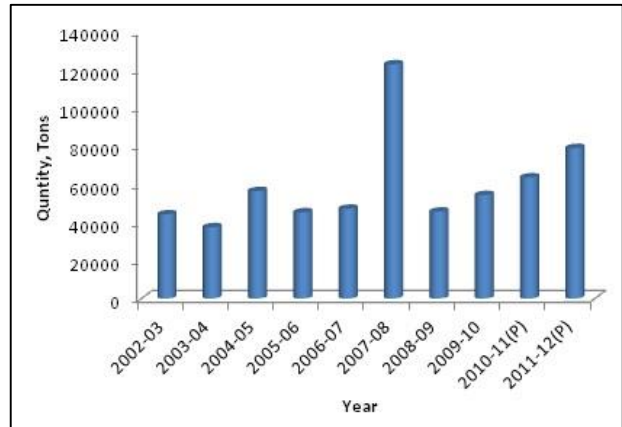


Fig 8. Import of all grades of bauxite

The average trend on the export and import values of bauxite during 2003-12 is shown in Fig.9. It can be seen from Fig. 9 that the export of bauxite to different foreign countries are significant during 2007 to 2009. The export is totally insignificant during 2010-12. In other way, it can be seen that the internal consumption of bauxite in various industries of India is significantly minimum during 2007-09 due to the priority in exporting of bauxite. The internal consumption of bauxite as given in Tables 3 and 4 indicate that alumina/aluminum industry was the principal consumer of bauxite, accounting for 87.5% consumption in 2008-09 followed by cement (9.5%) and refractory (3%). Gujarat was the main supplier of chemical, abrasive and refractory grade bauxite. Alumina plants draw supplies mostly from their captive mines. It is observed that high priority has been given to internal consumption of bauxite during 2010 to 2012 and hence the export of bauxite has minimized.

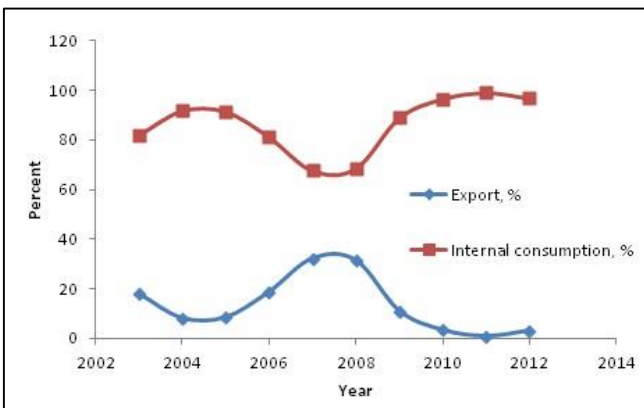


Fig 9. Trend on average values of bauxite export and import during 2003 -12

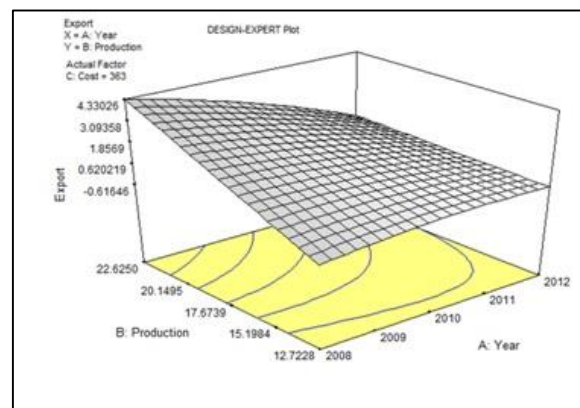


Fig 10. Design Expert plot for export (Lakh Ton) with reference to production vs Year

#### 4. Response Surface Methodology

It can be clearly seen from the design expert plot (Fig.10) for the export of bauxite with reference to production during the years 2008 -12 indicate that the export of bauxite is maximum during the year 2008 and further continuously decreasing from 2008-2012. This is due to the a fact that during the year 2008 the production is maximum and further the production is constantly is decreasing may be due to the demand of internal consumption or owing to decrease in market demand, rejection of mining lease by Government, non availability of royalty passes from Government, etc.



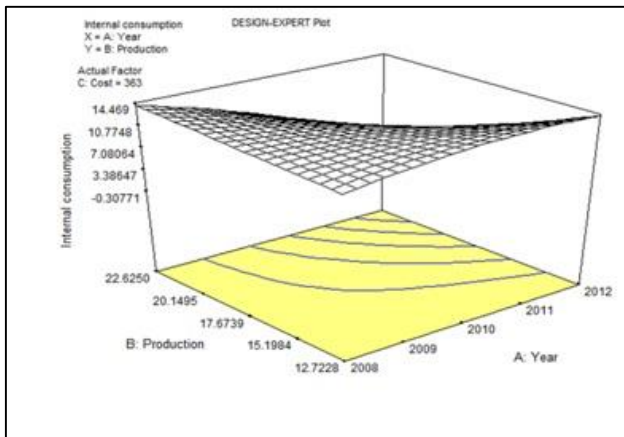


Fig 11. Design Expert plot for import (Lakh Ton) with reference to production vs Year

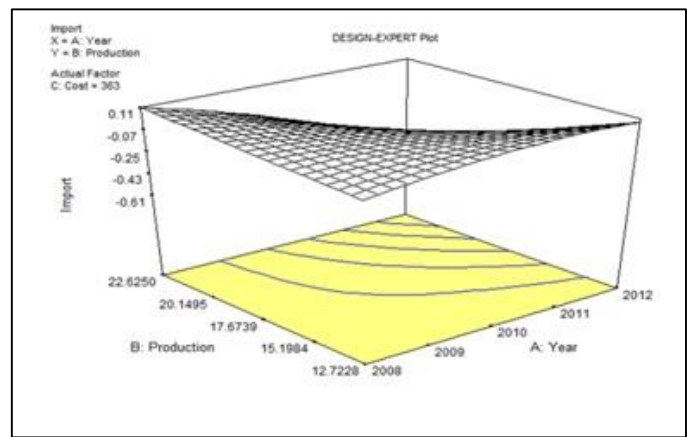


Fig 12. Design Expert plot for internal consumption (Lakh Ton) with reference to production vs Year

This observation can be supported from the Fig.11 on bauxite import data, which indicates that the imports of bauxite are also maximum during the year 2008. It has seen short down fall during 2009. Further the import values are marginally increased but not to the extent of the year 2008. The design expert plot shown in Fig.12 for the internal consumption of bauxite with reference to production during the years 2008 -12 indicate that the internal consumption is maximum during the year 2008 and then steadily decreasing. This may be due to a fact mentioned earlier that owing to decrease in market demand, rejection of mining lease by Government, non availability of royalty passes from Government, etc. The details of the production, export, imports and internal consumption value calculated from the ANOVAs equation using response surface methodology are given below:

- Export (In Lakhs Tons) = + 48.09 - 40.20 \* A + 13.47 \* B - 0.0000056 \* C - 0.0000030 \* A<sup>2</sup> + 0.0000227 \* C<sup>2</sup> - 11.26 \* A \* B,
  - R Squared value = 99.68%.
- Import (In Lakhs Tons) = - 4.974 - 7.282 \* A - 1.393\* B - 0.070\* C - 0.00000055\* A<sup>2</sup> - 0.00000056\* C<sup>2</sup> - 2.040\* A \* B,
  - R Squared value = 99.999%.
- Internal Consumption (In Lakhs Tons) = -111.4 - 146.5 A - 31.20 B - 0.0000205 C -0.0000111A<sup>2</sup> -0.000064\* C<sup>2</sup> - 410.4\* A \* B,
  - R Squared value = 96.32%.

## 5. Future Out Look

The data reveal that the resources for Indian bauxite suitable for metallurgical applications are sufficient but for refractory industry applications are very much limited. There is no substitute of bauxite for aluminium metal extraction on a large scale. However, calcined clay can be substituted for refractory bauxite but only with reduction in length of time and stock resistance. Sillimanite, alumina, silicon carbide, magnesite-chromite and carbon-magnesite refractories are the alternatives for high-alumina material but at higher cost. Silicon carbide and diamonds can substitute for fused aluminium oxide in abrasive use but again at higher cost. Synthetic mullite substitutes for bauxite-based refractories. Silicon carbide and alumina-zirconia are costlier substitutes for bauxite-based abrasives [2]. In view of this, many Government R & D organizations include CSIR, JNRDC etc., and public sectors include NALCO, BALCO, Vedanta, Aditya Birla etc are doing research for up gradation of low grade bauxite suitable for different industrial applications.

## 6. Conclusions

The Indian Bureau of Mines, The Government of India, has published a series of Mineral Year Books. In the present paper an attempt is made to retrieve the data or mined out the data from the Mineral year books of Indian Bureau of Mines with particular reference to the production strategies of Indian bauxites. The following conclusions are drawn from the data mining on production strategies of Indian bauxites:

- Resources of bauxite in the Indian country by grade wise indicate that about 86% resources are of metallurgical grade and 3% resources are for refractory and chemical grades. By States, Odisha alone accounts for 55% of country's resources of metallurgical grade bauxite followed by Gujarat (6%) suitable for refractory applications.
- The production of bauxite during 2007-08 is maximum 23000000t and subsequently decreased from the year 2008-12, specially during 2011-12 the production of bauxite is decreased to 1300000t. The production trend of bauxite specially refractory grade bauxite from Gujarat is significantly very high during the year 2008 whereas the production of metallurgical grade bauxite from the state of Odisha is less than 20 % during the year 2008 but >40% production of bauxite obtained during the year 2012.
- The data reveal that many Government R & D organizations include CSIR, JNRDC etc., and public sectors include NALCO, BALCO, Vedanta, Aditya Birla etc are doing research for up gradation of low grade bauxite suitable for different industrial applications. But the information available on this is not sufficient as per the present demand and hence Government has to give more stress on these aspects.

#### **ACKNOWLEDGEMENT**

The first author is thankful to Dr. Madhumita Parida, Chairperson of Aryan Institute of Engineering and Technology for her encouragement and forwarding this paper for publication.

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