

Role of stainless steel to combat corrosion in the Indian sugar industry

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Abstract

Corrosion is a fact of life in sugar mills and refineries. In India, losses due to corrosion in sugar factories are estimated to be around U\$250 million annually. This paper highlights the issue of corrosion studied in the Indian sugar industry and suggests the use of cost effective grades of stainless steels in equipment rather than the commonly used mild steel or expensive stainless steels. The lifecycle costs aspect and the issues in the operating environment in the sugar industry have been discussed.

Introduction

Corrosion is widely recognized as a major problem in the sugar industry. The Indian sugar industry has woken up to this problem and is now contemplating measures to address it. Rough estimates indicated that the losses due to corrosion in the Indian sugar industry amount to over Rs 10 billion¹ (US\$ 250 million) This paper reports on a study with the collaboration of the Sugar Technology Association of India, where experts from the sugar industry visited four sugar factories in different sugar producing states in India. The group also initiated experiments to assess the impact of corrosion and explored the possibility of developing competitively priced stainless steel (SS) grades for use in the sugar industry. It begins with a brief overview of the problem in sugar mills.

Corrosion in the sugar mills

Corrosion in sugar mills has been studied in great detail and a number of papers discuss this problem. The most common factors are:

1. Acidic environment
2. Abrasion / erosion

3. Use of chemicals
4. Acidic vapors
5. Galvanic corrosion
6. Off season corrosion
7. Surface finish

Apparently, mild steel is widely used in the manufacture of sugar processing equipment. However, the equipment made from mild steel has relatively low life, as it is prone to be corroded.

Following are the major points raised during the discussions at various sugar mills in India.

a) Productivity:

It was estimated that approximately up to 5% of productive time loss is due to corrosion related matter. However, there is no specific data available on stoppages due to corrosion because most of the failures are attended to during general stoppages.

b) Construction material:

Factories have attempted to experiment with various types of materials.

- Stainless steels are being used at carrier troughs, pump impellers and bodies, pipe lines, etc.
- FRP (fiberglass reinforced plastic) lining has been tried at joints of mill gutters & trays etc but met with limited success due to high cost of repair/ replacements.
- PVC pipelines have been used for mill imbibition piping but leakages have been observed quite frequently.

b) Lifecycle costs:

- It was apparent that knowledge on stainless steel grades was sketchy.
- Most of the applications of stainless steel in the sugar industry involve the use of grade 304, which is very expensive. Doubtless the main reason for lack of use of higher-grade materials is the perception of high cost.

c) Other issues:

- Measures for removing corrosive materials from different equipment.
- Equipment requiring special coatings, e.g. big pump impellers like spray and injection water pumps.
- Suitable material for corrosive environment (like SO₂ piping, etc).
- Selection of roofing material over the process area, which has a life of only 1 - 2 years.

The foregoing identifies the appropriate grade for each application process and optimize costs.

Major findings

Findings from the discussions held with the operating personnel at the four factories are summarized below:

1. Areas experiencing abrasion, like cane carriers, rake type

carriers, bagasse carriers etc have been substituted with stainless steels, resulting in the improvement in life of the equipment from 1-2 seasons to 9-10 seasons.

2. Juice pipelines when replaced with stainless steels have been found to be working satisfactorily even after 9 years whereas the earlier mild steel pipes needed to be replaced every 2-3 years.
3. Substitution of stainless steel in tanks, e.g. primary juice tanks, whirler tanks, screened juice tanks, unscreened juice tanks has resulted in the reduction of both in maintenance and replacement costs.
4. Use of stainless steel has become a very common practice in Donnelly chutes.
5. Pitting has been observed in evaporator tubes (1-2% of the tubes, every year). Few mills have overcome this problem by improving the exhaust of noxious gases (providing extra exhaust outlets).

A summary comparison of the estimated increase in life in various equipment due to substitution with an appropriate grade of stainless steel is shown in Figure 1.

Factors contributing towards corrosion in sugar factories

- *Surface finish:* improper surface preparation increases the corrosion rate.
- *pH:* pH in acidic range tends to disturb the protective layer formed by chromium oxide.
- *Presence of chlorides and sulphides:* these are both highly corrosive
- *Flow rate:* high flow rates removes protective surface films through wear, and this usually hastens corrosion.
- *Water quality:* very important. Aggressive ions which accelerate corrosion are Cl⁻, SO₄²⁻.

Recommended equipment for substitution with stainless steels

Listed below are the range of equipments which will benefit from the use of appropriate grade of stainless steel. The recommended grades as well as the life cycle cost comparison with the existing material are mentioned later. The estimated savings in annual replacement material costs due to upgrading with appropriate stainless steel grade can go upto even 50%.

- Cane carrier side plates
- Cane carrier chain links
- Rake type inter carrier, Wear Pads troughs and rakes
- Mill imbibition piping
- Donnelly chutes
- Juice pump body and impellers (up to sulphited juice pump)
- Mill juice gutters
- Whirler tanks, screened juice and unscreened juice tanks
- Bagasse carrier trough
- Raw juice lines
- Clarifier mud scrapers
- Juice sulphiter
- SO₂ gas pipeline
- Rotary vacuum filter filtrate lines and tanks

Figure 1. Lifecycle comparison of mild steel (MS) vs appropriate stainless steel grade (SS) in various sugar processing equipment

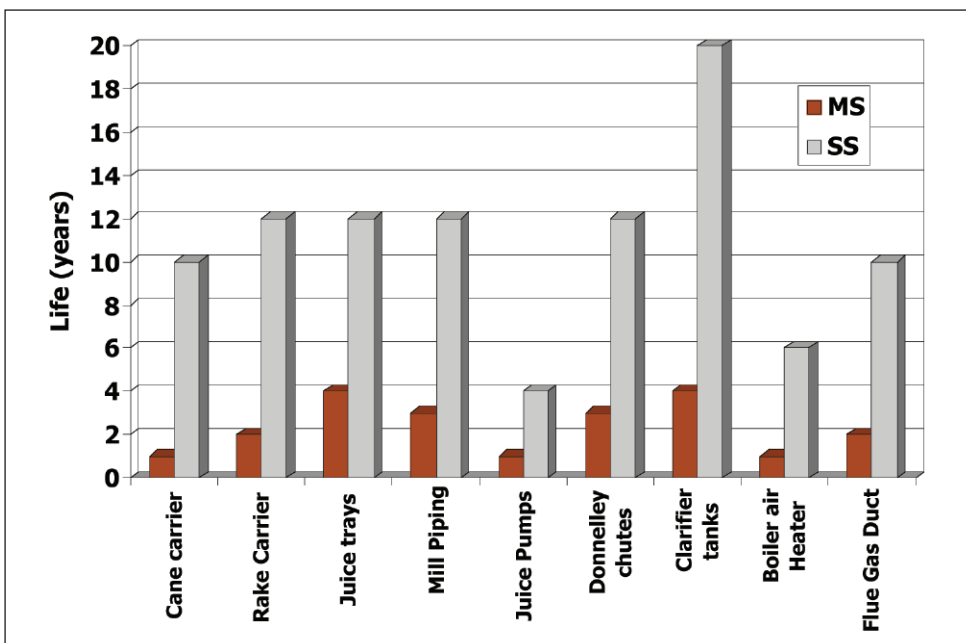


Table 1. Stainless steels used in sugar industry

Type	Common Grades	Typical Applications
Cr-Ni Austenitic (300 Series)	304, 316	Welded and formed structures, corrosion resistance applications, tubes, vessels, etc.
Cr-Mn Austenitic (200 Series)	JSLAUS, J204Cu, J4	Welded and formed structures, Cane carriers, milling equipment, corrosion resistance applications, tubes, vessels, etc.
Ferritic	409M	Cane carriers, other dry applications

oxide, which prevents further oxidation of iron (or rust). This top chromium oxide layer is self-repairing and as soon as it comes in contact with the air (oxygen) it reforms itself if it is damaged.

Stainless steel grades may contain additional elements like nickel, manganese, carbon, nitrogen, silicon, etc. Alloying with nickel, manganese, nitrogen help in forming austenitic structure of steel which improves properties like formability, weldability, etc.

Criteria for selection of suitable stainless steel for sugar industry

Typical properties which go into the selection of material are :

- Mechanical / chemical properties (imparting features such as strength)
- Fabricability and weldability
- Corrosion performance
- Wear performance

Besides the above factors, cost of using a particular grade is also a concern.

Table 2. Mechanical properties of different grades of stainless steel

Co. Standard \ Grade	J4	204Cu	JSL AUS	409M	304
Yield Strength (MPa) (minimum)	325	310	265	275	205
Ultimate Tensile Strength (MPa) (minimum)	650	650	620	450	515
% Elongation (minimum)	40	40	40	20	40
Hardness (HRB) (max)	98	100	95	90	92

- Juice heater covers
- Juice heater condensate lines
- Vacuum crystallizer top dome
- Pan and last evaporator vapor lines
- Condensate lines for evaporator
- Molasses gutters
- Partition plates inside continuous centrifugals
- Centrifugal basket ribs
- Hopper trough and base plates

Tubes are another area which is of major concern to the sugar industry. Due to the high cost of the stainless steel 304 grade (consequent to the three fold increase in nickel prices last year), the industry is looking for the alternative grades. Jindal Stainless has been in the forefront of developing a range of Cr-Mn-N (200 series) grades, which have properties similar (mechanical properties like strength are even better) to the 300 series but are more economical.

Types of stainless steels

Stainless steel grades are essentially alloys of iron with more than 10.5% chromium. This chromium forms a passive film of chromium

Mechanical and chemical properties

The Cr-Mn-N (200 series) stainless steels are austenitic in structure, which has the well-known benefits of formability, weldability, cold workability, etc. Besides, due to addition of nitrogen, these steels are much more stronger than the 300 Series which promotes use of thinner sheets (and hence light weight structures).

The lower nickel content, which is replaced by an appropriate balancing chemistry of Mn-N, helps in reducing the costs appreciably. Tables 2 and 3 depicts the mechanical properties and chemical composition of the various grades of stainless steel.

Fabricability and weldability

Austenitic stainless steel grades are known for their better weldability, and formability. These are two major operations for component and machinery fabrication in sugar industry. An extensive weldability study has been conducted by Jindal Stainless Ltd on austenitic 200 series grades, which suggest that grades under investigation are amenable to standard welding practices, followed in industry. Table 4 summarizes the recently concluded weldability tests.

Table 3. Chemical composition of recommended grades of stainless steels for sugar industry

Grade		Cr	Ni	C	Mn	Cu	N	P	Si	S	Fe
J4	Min	15	1	-	8.5	1.5	-	-	-	-	Balance
	Max	16.5	2	0.1	10	2	0.2	0.06	0.75	0.03	Balance
J204Cu	Min	16	1.5	-	6.5	2	0.1	-	-	-	Balance
	Max	17.5	3.5	0.1	9	4	0.2	0.06	0.75	0.03	Balance
JSL AUS	Min	16	4	-	6	1.5	-	-	-	-	Balance
	Max	18	6	0.08	8	2	0.1	0.06	0.75	0.03	Balance
409M	Min	10.8	-	-	0.8	-	-	-	-	-	Balance
	Max	12.5	1.5	0.03	1.5	-	0.03	0.03	1.0	0.03	Balance
304	Min	18	8	-	-	-	-	-	-	-	Balance
	Max	20	10.5	0.08	2	-	0.1	0.045	0.75	0.03	Balance

Table 4. Compatibility of welding practices of various stainless steel grades

Welding Methods	Applicable Thickness (mm)	J4	J204Cu	JSLAUS	304	Applications
Shielded Metal arc	t>0.8	1*	1	1	1	Butt welding, corner reinforced welding, wide diameter pipe
TIG Welding	0.5<t<3	1	1	1	1	Butt Welding thin sheets, corner reinforced welding, narrow diameter pipe
MIG welding	t>3	1	1	1	1	Thick sheet/ plate welding, corner reinforced welding, wide diameter pipe.

*indicates widely used practice. That is no failure was observed during the bend test.

Corrosion performance comparison of stainless steel with other materials

Table 5 shows the corrosion performance of various stainless steel grades in relation to mild steel at various temperatures. It is apparent from the table that even the cheapest grade of stainless steel has much lower corrosion than mild steel.

The corrosion resistance of grade J4 makes it suitable for most applications in the sugar industry, particularly in circumstances where corrosion rates are likely to be moderate, e.g. tanks, vessels, pipelines cane carriers/ bagasse conveyors, the evaporators and pan bodies. The advantage of using this grade steel in the manufacture of tanks and vessels is that not only will they be of lower thickness due to both better properties and lower corrosion allowances, but also that the supporting structure weight can be reduced appreciably. Further, many problems like galvanic corrosion between the tubes and the plate can be eliminated resulting in further savings.

Grade JSL-AUS has been found to be a cost effective grade for applications facing higher corrosion like the tubes for evaporators and pans.

Wear performance

Another area of interest for designers of equipment in the sugar industry is the wear resistance of the material, particularly in the sugarcane handling area. In this aspect stainless steel have much better properties compared with other materials. In extensive trials conducted by Indian railways for the wagons handling coal during the last 5 years, it was found that its life was extended by more than 3-5 times than that of mild steel. Besides, its corrosion resistance is 250-times that of unpainted mild steel. This combination has resulted in substantial reduction in the maintenance cost and increase in life for the railway wagons. Similar benefits can be achieved in the sugar industry. Some compar-

Table 5. Comparison of corrosion performance of mild steel with various grades of stainless steel in sugarcane juice

Corrosion rate (mmpy) at various temp. in Sugarcane Juice			
Grade	At 25°C	At 70°C	At 100°C
Mild steel	0.19	0.46	3.12
409	<0.001	0.003	0.003
J4	<0.001	<0.001	<0.001
204Cu	<0.001	<0.001	<0.001
JSL-AUS	<0.001	<0.001	<0.001
304	<0.001	<0.001	<0.001

tive performance of various grades is shown in Figure 2.

It is apparent from Figure 2 that the grade J4 is the optimum grade when cost is also considered in applications involving wear resistance. Combined with the austenitic structure, which helps in fabrication and welding, the better corrosion resistance to sugarcane juice, it certainly has a significant edge over mild steel and 409.

Lifecycle costs of equipment

The economic benefits of choosing stainless steel can be highlighted by an analysis of life cycle costs¹² (LCC) - the total costs involved with installing, operating and maintaining a piece of plant over its complete life. In case of pipelines, the additional benefits, which will

Figure 2. Comparison of fretting wear rates of different grades of stainless steels

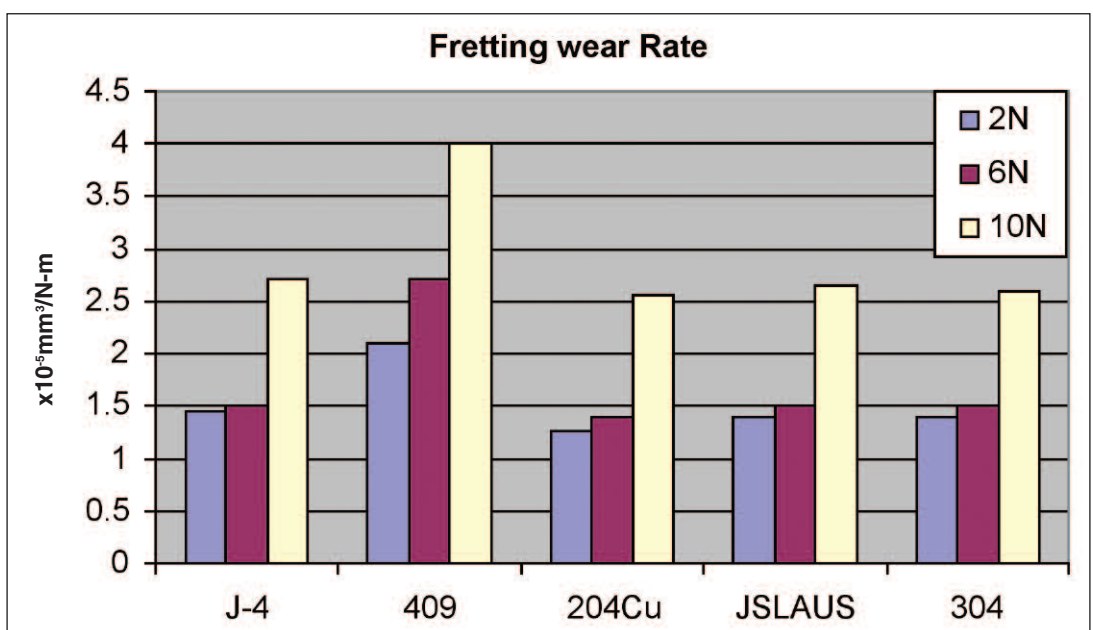


Table 6. Lifecycle costing due to use of appropriate materials

S. No	Location	Existing Material				Proposed Material							Material Savings \$ per year	% Savings per annum
		Material	Thick-ness mm	Estimated wt. kg	Life (Based on practical experience)	Material cost/ year	Proposed Material	Price- \$/KG	Proposed thk mm	Proposed wt. kg	Expected life (Years)	Proposed Material cost/yr		
1 US\$= Rs 40														
Cane carrier (2.6M x 75.5M)														
1	Cane Carrier Chain Links	M.S.	18	6630	20% rejected every year	1,028	J4	2.25	12	4420	5% rejected every year	497	530	52%
2	Cane Carrier Side plate	M.S.	8	4710	2 years	1,825	J4	2.25	5	2944	12	552	1,273	70%
3	Rake type inter carrier	M.S.	8	1793	25% replacement	347	J4	2.25	4	897	12	168	179	52%
4	Mill imbibition piping (150m)	M.S. CLASS C	5.4	3195	3 years	2,476	J4	2.25	3	1775	12	333	2,143	87%
5	Donnelly Chutes (4mx 4 x2)	M.S.	8	5216	2 years	2,021	JSLAUS	3.75	4	2624	12	820	1,201	59%
6	Mill Juice gutters, juice trays (50 sq. M)	Aluminium	8	550	2 years	1,100	JSLAUS	3.75	4	785	12	245	855	78%
7	Whirler tanks, screened juice and unscreened juice tanks	M.S.	8	?	4.5 years due to low pH material	-	J4	2.25	4/5		15			
8	Bagasse Carrier through (200m)	M.S.	6	18800	1 year	14,570	J4	2.25	4	12533	5	5,640	8,930	61%
9	Raw juice line from mill to Juice Sulphiter (100m)	M.S.	-	2130	1 season	1,651	JSLAUS	3.75	-	1065	5	799	852	52%
10	Rotary vacuum filter Filtrate lines and Tanks	M.S.	-	1000	1 year	775	JSLAUS	3.75	-	700	4	656	119	15%
11	SS tubes in Evaporators and Tube plate (50Ton)	SS-304	1.2	50000	10	29,625	JSLAUS	3.75	1.2	50000	10	18,750	10,875	37%
12	Juice Heater Condensate lines (80M)	M.S.	5.4	1704	1	1,321	JSLAUS	3.75	3	947	5	710	611	46%
13	Vacuum Crystallizer Topdome (3nos)	M.S.	6	1500	Pitting/ leakage observed every year	1,163	JSLAUS	3.75	4	1000	5	750	413	35%
14	Pan and last evaporator vessel Vapour lines	M.S.	8	15760	2	6,107	JSLAUS	3.75	5	9840	10	3,690	2,417	40%

NOTE:
 1. Only material cost considered. If Labor and Fabrication costs for replacement are added, additional savings will be possible
 2. Prices are basic prices ex-works, approximate as on the date 1st May 2007, for 3mm HRAP coils, at Jindal Stainless Limited.
 3. MS is Mild Steel

be available, are lower power consumption because of reduced friction as a result of reduced corrosion and smoother finish.

Table 6 calculates the advantages in terms of material cost only. These savings will be multiplied when the labor and fabrication costs are considered and the dismantling and replacement costs are added. Also, scrap value of the materials have been neglected, which also generates additional revenue as stainless steel scrap can be sold at more than 50% of its mill product value.

Conclusions

Stainless steels are becoming mandatory for equipments involved in the sugar manufacturing in many countries. Our studies in several sugar factories in India have confirmed that while the use of stainless steel appears to be costly, it is indeed cost-effective when measured in terms of the life of an equipment compared with mild steel. Availability of the newer Cr-Mn Series of stainless steels have further improved the cost-benefit ratio by reducing the upfront investments while maintaining the desired properties and not compromising on the performance in the sugar industry environment.

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