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The Application of High Corrosion Resistance Stainless Steel YUS270 in Food Processing Facilities and Equipment

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Abstract

Stainless steel is used in food processing facilities and equipment. However, in environments that are high in salinity content, such as soy sauce, localized corrosion has become a problem even with type SUS 316L. On the other hand, for storage tanks carbon steel with lining, FRP, etc. have been applied. Recently, however, the conversion to stainless steel is increasing partly in consideration to environment problems, etc. Consequently, the need for high-corrosion-resistance stainless steel is increasing. Nippon Steel developed a technology for estimating the occurrence time of localized corrosion by means of electrochemical corrosion evaluation and is promoting the wider use of highly corrosion resistant YUS270 steel. This paper outlines the circumstances surrounding this issue.

1. Introduction

Stainless steel has been extensively used in food processing facilities and equipment from a sanitary standpoint. However, soy sauce, dressing, dripping, and other seasonings contain high concentrations of salt. This renders type SUS 316L vulnerable to pitting, crevice corrosion, and stress corrosion cracking (SCC)[1], which sometimes leads to the suspension of facility operation. On the other hand, large-scale tanks of unrefined soy sauce in soy sauce manufacturing plants have used resin-lined carbon steel thus far. However, the use of stainless steel is being studied because of increases in the cost of maintenance, including repair, and the issues regarding endocrine disruptors relating to ever stricter environmental regulations.

Accordingly, electrochemical corrosion evaluation tests of various kinds of stainless steel were carried out in actual soy sauce and unrefined soy sauce tanks. YUS270 (20%Cr-18%Ni-6%Mo-0.7%Cu-0.2%N) was found to be a material that is suitable for such tanks. The application of this material to the food industry is therefore under development over a wide range. This paper deals with the application of YUS270 to the soy sauce manufacturing plant which is proposing to minimize LCC (life cycle cost) in terms of both the replacement of the resin-lined carbon steel of an unrefined soy sauce tank with stainless steel and the security of the longer service life of pipe.

2. Chloride ions in food and the corroded state of stainless steel

In high salt-content foods, the state of corrosion differs in relation to the concentration of chloride ions, temperature and time. In general, a sport dink contains 100 to 600 ppm chloride ions, and pitting is found in heat exchangers made of type SUS 316L under high-temperature conditions. However, type SUS 316L is sufficiently resistant to vinegar that contains acetic acid, which is weak acid. However, the vinegar used for sushi that contains 5 to 9% salt causes pitting and crevice corrosion in type SUS 316L. Furthermore, SCC is sometimes found when extracting essence at high temperature in the manufacture of soup containing about 5 to 10% salt. Additionally, soy sauce, dressing, and dripping, all contain about 15% salt,

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which cause pitting and crevice corrosion in the processes of brewing and storage for a long period of time. The process of heat treatment is subjected to the severest corrosion environment in which pitting, crevice corrosion, and SCC tend to occur.

3. Development of the Technique of Applying YUS270 to Soy Sauce Manufacturing Plants

The unrefined soy sauce tanks employed in soy sauce manufacturing plants are not only subjected to such corrosive environment as above-described, but they are also difficult to replace easily because of the large scale nature of such facilities. In the application of stainless steel, it should be reliable enough for prolonged resistance to corrosion equivalent to the service life of the equipment. On the other hand, corrosion tests regulated by JIS (Japan Industrial Standard) uses a standard solution. This means that testing is limited only to relative evaluation among various kinds of stainless steel, making it impossible to evaluate whether it can be used in actual soy sauce manufacturing environment. The immersion test in soy sauce manufacturing plants takes such a long time that it is unsuitable for use in deciding when to invest. This has led to the development of a method of assuming the time required until crevice corrosion occurs (called an incubation time) using the electrochemical corrosion test.

3.1 Concept of material life based on crevice corrosion damage

The life of material due to crevice corrosion can be divided into the incubation time of crevice corrosion and the time when crevice corrosion keeps propagating until it pierces the tank wall (called propagation time of crevice corrosion) (see **Fig. 1**). It is important for the food industry to control the elution of metal ions to a minimum and prevent corrosion. If the incubation time of crevice corrosion is sufficiently long, stainless steel can be applied to the actual plant where periodic cleaning is to be carried out.

3.2 Estimation of incubation time of crevice corrosion

To simulate the environment inside the "moromi" an unrefined soy sauce solution was purchased, and three types of stainless steel (SUS 316L: 17Cr-12Ni-2.5Mo, SUS 329J4L: 25Cr-7Ni-3Mo-0.2N, YUS270) were selected to prepare test pieces. Then, electrochemical tests were carried out at 45 °C using the test pieces with welded parts which are most vulnerable to corrosion and the test pieces with crevice.

3.2.1 Measurement of natural potential of stainless steel in unrefined soy sauce solution

A potential (called natural potential: E_{sp}) was measured which the stainless steel test piece stably present in a passivated state exhibits in the unrefined soy sauce solution. No significant difference was observed among the three types of stainless steel. E_{sp} = –136 mV to –164 mV (vs.Ag/AgCl, KCl saturated) (refer to **Fig. 2**).

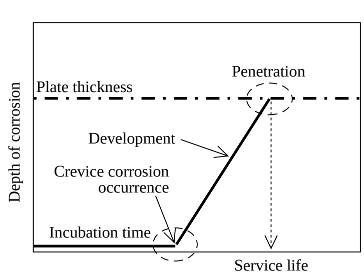

Fig. 1 Conceptual drawing of crevice corrosion occurrence and development

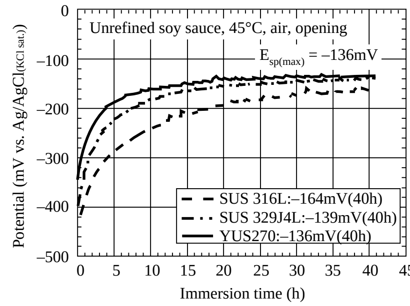

Fig. 2 Results of measurement of natural potential in unrefined soy sauce solution

3.2.2 Measurement of at incubation time of crevice corrosion under potentiostatic condition

The incubation time of crevice corrosion can be expressed in terms of the function of potential. The changes over time of the density of current passing through the material were measured with the potential of the material maintained at controlled potential level using the external power source. The controlled potential value in this case should be nobler than the crevice repassivated potential peculiar to the material (lower-limit potential of crevice corrosion growth). If the controlled potential value is base, the current density becomes lower. This means that the material does not develop crevice corrosion regardless of the lapse of time. If the potential is rendered noble to some extent, the current density abruptly or gradually increases. This corresponds to an increase in reaction velocity, so crevice corrosion can therefore be judged to have started. It should be noted that the incubation time of crevice corrosion was obtained in terms of the time corresponding to current density 10^{-5}A·cm^{-2} (10 μA/cm^2) equivalent to corrosion velocity 0.1 mm/y, generally used for judging the corrosion resistance of stainless steel (see **Fig. 3**).

3.2.3 Estimation of incubation time of crevice corrosion in natural immersion state

When the line of interrelation between the above-described stable potential value and the incubation time of crevice corrosion is extrapolated potenstaticly, the time at the intersecting point can be considered to correspond to the incubation time of crevice corrosion in the natural state. The incubation time of crevice corrosion (an assumed value) in the "moromi" (unrefined soy sauce solution) environment is 20 years for YUS270 in contrast to 33 hours for SUS 316L and 1.5 years for SUS 329J4L. This leads us to judge that YUS270 can be used satisfactorily for an unrefined soy sauce tank even in consideration of the variations in operation and measured data (see **Fig. 4**).

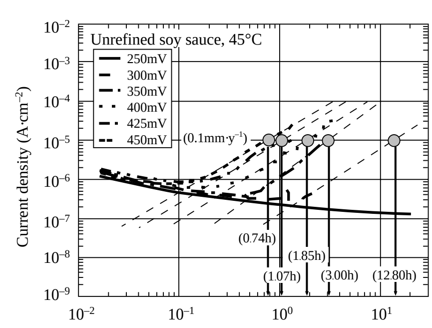

Fig. 3 Results of electrolytic test of YUS270 welded parts at potentiostatic

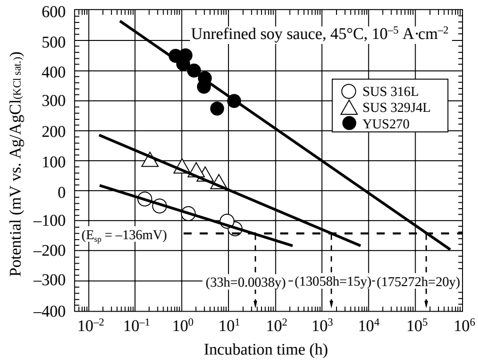

Fig. 4 Results of evaluation of incubation time of crevice corrosion (assumed) (welded parts included)

4. Application of YUS270 to a Soy Sauce Manufacturing Plant

4.1 The restraint of LCC minimization

LCC was evaluated for two cases in which resin-lined carbon steel and SUS 316L pipe were used for a 240-kL unrefined soy sauce tank, respectively. A resin-lined carbon steel tank is low in initial investment amount due to the difference in material cost. However, it becomes higher in cost than that made of YUS270 because of an increase in maintenance costs including frequent lining repair costs based on an assumed service life of 30 years, which is below 80% of the conventional cost. If the cost of the SUS 316L pipe, assuming it is replaced every three years, is calculated, YUS270 reduces the cost to about 30%, which is a dramatic reduction in costs (see **Fig. 5**).

4.2 Application examples and completion of product menu

Tank and pipe delivered so far to soy sauce manufacturing plants and chemical seasonings manufacturing plants, are working as expected in terms of corrosion resistance. For example, a hitherto-used SUS 316L joint tube, 3 mm thick, developed crevice corrosion in about three months, and was replaced every year. However, YUS270 did not show any trace of corrosion six months after its use.

To provide this effect to more customers, we are expanding the product menu of YUS270 to replace carbon steel sheets. It has been extended to tubes, joints, sanitary tubes, valves, and bars and configuring speedy delivery systems for distribution.

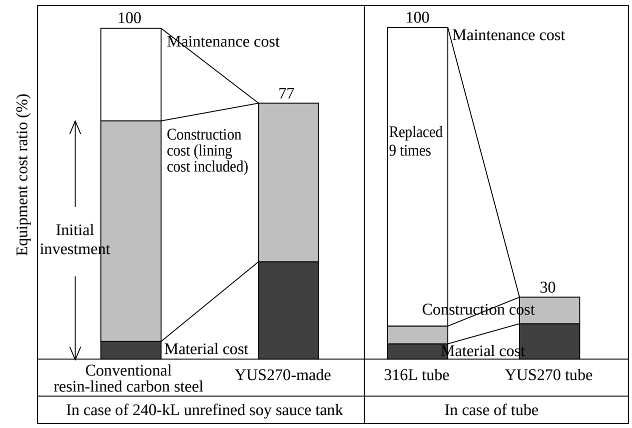

Fig. 5 Comparison of LCC between conventional method and when YUS270 was applied

5. Conclusion

The expectations of consumers toward the improvement of safety and reliability of the food industry have been increasing. In addition, stainless steel is expected to play an important role as material in wielding the influences on the improvement of the natural environment, including issues related to endorine disruptors and recyclability. It is firmly believed that the application of YUS270 to food processing facilities and equipment, particularly to highly corrosive foods, will contribute greatly to the improvement of their safety and reliability as well as to the reduction of cost in the food industry. We expect to prepare a guideline on the selection of proper kinds of steel for the food industry along with the expansion of their applications to the new fields including medical plant application in the near future.

Reference

1) Takizawa: Corrosion Examples and their Countermeasures. First Edition, Tokyo, Sogo Gijutsu Center, 1994, p.327