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# Analysis of AISI 304 Tensile Strength as an Anchor Chain of Mooring System

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**Abstract.** The background of this research is the use of mild steel (i.e., St37) as anchor chain that works on the corrosive environment of seawater which is possible to decrease its tensile strength. The longer soaked in seawater, the more significant the lowering of its tensile strength. Anchor chain needs to be designed by considering its tensile strength and corrosion resistance, so it's able to support mooring system well. The primary purpose of this research is obtaining the decreasing of stainless steel 304 (AISI 304) tensile strength which is corroded by seawater as anchor chain of the mooring system. It is also essential to obtain the lifetime of AISI304 and St37 as anchor chain with the same load, the corrosion rate of AISI 304, and St 37 in seawater. The method which was employed in this research is an experiment with four pieces of stainless steel AISI 304, and of St 37 corrosion testing samples, six pieces of stainless steel 304, and six pieces of St 37 for tensile testing samples. The result of this research shows that seawater caused stainless steel AISI 304 as anchor chain has decreased of tensile strength about 1.68 % during four weeks. Also, it indicates that AISI 304 as anchor chain has a lifetime about 130 times longer than St 37. Further, we found that the corrosion rate of stainless steel 304 in seawater is 0.2042 mpy in outstanding category, while the St 37 samples reached up to 27.0247 mpy ranked as fair category. This result recommends that AISI 304 more excellence than St 37 as anchor chain of the mooring system.

**Keywords.** AISI 304, corrosion rate, St 37 and tensile strength.

## 1. Introduction

Indonesia's cruise accident tends to increase for every year. During 2010 – 2016, it had occurred 54 cruise accidents that caused 337 people died or missed, and 474 people injured. Cruise accident can be drowning, burning or exploding, crashing, and grounding [1]. This matter needs to get attention about the importance of designing of an anchor chain for supporting mooring system safety. Anchor chain is a tool that is used between anchor and ship so the movement of the ship can be decreased. Anchor chain has a vital role in mooring system. The performance of mooring system depends on the strength of anchor grip in the seabed, and the strength of anchor chain to hold the ship speed.

Anchor chain is usually designed from mild steel with tensile strength about (37 to 55) kg·mm<sup>-2</sup> and strain about (20 to 30) %. St37 contains carbon of 0.17 %, it has tensile strength of (36.7 to 52) kg/mm<sup>2</sup> and strain of (16 to 24) % [2]. Corrosion testing of carbon steel in seawater shows that corrosion resistance of carbon steel is very low [3]. Compared to the AISI 304, the corrosion resistance of St 37 is lower than corrosion resistance of AISI 304. The AISI 304 consist of (18 to 20)



% chromium [4]. Corrosion rate testing of AISI 304 in corrosive solutions such as NaOH, KOH, and NaCl shows the corrosion resistance of (0 to 0.0234) mpy in the excellent category [5]. AISI 304 testing of welded strength in seawater shows that it has occurred decreasing of tensile strength about 2.9 % [6].

Decreasing of anchor chain's tensile strength may cause the breaking of anchor chain while anchoring. The breaking of anchor chain may cause ship can't be anchoring, or mooring system is failing. The breaking of anchor chain also caused economically disadvantage because when anchor chain is breaking, then anchor will be drowned through the anchor chain. If anchor chain is well designed, the mooring system can be supported well too. Anchor chain is designed for considering the loads, safety factor, corrosion resistance, and allowed of tensile strength. One of the purposes of this research is obtaining the strengths of St 37 and AISI 304. By identifying the strengths ratio of St 37 and AISI 304, it could be expected that AISI 304 can be used to replace St 37 as an anchor chain.

## 2. Materials and methods

ST 37 and AISI 304 were used as samples. There are two methods to characterize the samples: mass loss method and tensile testing. Mass loss method was used to measure the corrosion rate, and tensile testing was used to measure the strengths of ST 37 and AISI 304. Detailed information on the parameters used for testing the tensile strength of St 37 AISI 304 is shown in Table 1. The data of corroded tensile testing samples were compared with tensile testing of non-corroded samples. Corrosion testing data were used to determine the corrosion rate and its lifetime. Meanwhile, tensile testing data was used to analyze the decreasing of tensile strength.

**Table 1.** Parameters used in the testing of St 37 and AISI 304 tensile strength in seawater

Condition	Value
Exposure times	168 h to 672 h
Temperature	25 °C
Relative humidity	72 %
Air pressure	960 mbar

## 3. Results and discussion

The corrosion rate of AISI 304 in seawater is about (0.1804 to 0.2491) mpy (see Table 2). The average corrosion rate of AISI 304 is about 0.2042 mpy or 0.000518 mmpy. The corrosion resistance of AISI 304 in seawater belongs to the outstanding category. This result is in line with the other study [7]. The existence of (18 to 20) % chromium, caused AISI 304 resists to the corrosive environment [4]. The chromium in AISI 304 can bind spontaneously with oxygen, and it forms a passive film that can protect AISI 304 from the environment [8].

**Table 2.** Corrosion rates of AISI 304 on seawater

Sample	Time (hour)	Surface Area (in <sup>2</sup> )	Weight Loss (mg)	Corrosion Rate	
				mpy	mm/y
#A1	168	0.8123	0.4	0.1949	0.00050
#A2	336	0.7679	0.7	0.1804	0.00046
#A3	504	0.8909	1.3	0.1925	0.00049
#A4	672	0.7944	2.0	0.2491	0.00063

As seen in Table 3, St 37 corrosion rates in seawater is about (24.3341 to 31.8751) mpy. The average corrosion rate of St 37 is 27.0247 mpy or 0.068642 mmpy. For this value, the corrosion resistance of St 37 belongs to a fair category, which caused by the 0.17 % carbon content in St 37. The carbon content of St 37 is 47.06 % bigger than AISI 304 [2]. The role of carbon in the material is to

increase the mechanic strength, but it can decrease the corrosion resistance [9]. Different results about the comparison of corrosion rates of St 37 and AISI 304 were obtained when both materials were immersed in molten zinc bath [10]. Available high carbon in steel resulted in forming thick layers on the surface of St 37 and reducing the corrosion. In addition, St 37 has no chromium content so it cannot create a passive film to protect the material from the corrosive environment. High carbon content and no chromium content in St 37 caused corrosion resistance of this material lower than AISI 304. From the other study, the calcium carbonate precipitate observed after immersion in seawater probably cover the surface of material more effectively and may, therefore, be a better barrier against from corrosive environment [11].

**Table 3.** Corrosion rates of St 37 on seawater

Sample	Time (hour)	Surface Area (in <sup>2</sup> )	Weight Loss (mg)	Corrosion Rate	
				mpy	mm/y
#B1	168	0.7990	62.9	31.8751	0.08096
#B2	336	0.7885	104.8	26.9081	0.06835
#B3	504	0.7921	146.6	24.9817	0.06345
B4	672	0.7921	190.4	24.3341	0.06181

The tensile strength of St 37 and AISI 304 is shown in Table 4. It was observed that AISI 304 that corroded in seawater has decreasing of tensile strength about 1.68 %. Meanwhile, St 37 has reduced of tensile strength about 17.79 %. The lowering of tensile strength in AISI 304 is lower than St 37, so AISI 304 will has a lifetime longer than St 37. The difference of the decreasing of tensile strength is affected by variation of material corrosion rate. Furthermore, the tensile strength reduced is directly proportional to corrosion rate [12].

**Table 4.** The tensile strength of St 37 and AISI 304

Material	Not Corroded	Corroded in Seawater	Difference (%)
	$\sigma_{\max}$ (kg/mm <sup>2</sup> )	$\sigma_{\max}$ (kg/mm <sup>2</sup> )	
St 37	32.83	26.93	17.97
AISI 304	68.20	67.05	1.68

The function of anchor chain in many types of the ship is to hold the movement of the ship. Anchor chain is made with particular specification considering the prevailing standard. The scales of tensile strength that has to be held by anchor chain are based on the type of material and its diameter. Based on carrying loads and breaking loads data issued by Bureau Veritas, one of the anchor chains has to carry the 51 kN maximum load.

The force that works in anchor chain is a shear force; then it needs to be determined the maximum shear strength that can be received by each material. Maximum shear strength can be determined by [13]:

$$t_{\max} = 0.80\sigma_{\max} \quad (1)$$

The allowed of shear strength has to be determined to design the dimensions of the anchor chain. The allowing of shear strength can be determined using Equation 2 [13]:

$$\tau_{\text{allow}} = \frac{t_{\max}}{sf} \quad (2)$$

if breaking load of anchor chain is 51 kN or 5198.77 kg, then the diameter of chain can be determined using Equation 3 [13]:

$$A = \frac{F}{\tau_{\text{allow}}} \quad (3)$$

By using the Equation 1 to Equation 3, the maximum shear strength, the permission of shear strength, and the chain diameter of St 37 and AISI 304, can be shown in Table 5.

**Table 5.** The tensile strength of St 37 and AISI 304

Material	$\sigma_{\max}$ (kg/mm <sup>2</sup> )	$\tau_{\text{allow}}$ (kg/mm <sup>2</sup> )	diameter (mm)
St 37	26.26	15.72	20.50
AISI 304	54.56	32.67	11.02

From the calculation above, it is known that to hold the loads about 51 kN, it is needed minimum diameter about 20.50 mm for St 37 and 11.02 mm for AISI 304. The diameter of AISI 304 is 53.75 % smaller than the diameter of St 37 for same loads. Anchor chain is designed to hold certain load with certain lifetime. To design the lifetime, it needs a corrosion allowance that compensates for corroded material. If the corrosion allowance is 0.05 mm of each material, then the lifetime of each material as anchor chain can be determined by Equation 4 [14]:

$$CA_{\text{AISI304}} = CR \times LT \times 2 \quad (4)$$

where CR is corrosion rate, LT is a lifetime.

The lifetime can be obtained by using Equation (4) based on the data of corrosion rate of Table 2 and Table 3. The tensile strength and the lifetime of both samples are depicted in Table 6.

**Table 6.** The tensile strength of St 37 and AISI 304

Material	CR (mmpy)	LT (year)
St 37	0.067356	15.72
AISI 304	0.000518	0.37

It is observed that lifetime of AISI 304 is longer about 130.43 times than St 37. Therefore, AISI 304 exhibits an excellent performance compared to St 37 as anchor chain. Lifetime prediction of steel structure in the marine environment is a challenging task for corrosion engineers either for existing or new structures to be constructed [15].

#### 4. Conclusions

Seawater caused AISI 304 corroded about 0.2042 mpy for four weeks, and it creates the decreasing of its tensile strength of about 1.68 %. The lifetime of AISI 304 is nearly 130 times longer than St 37. The corrosion rate of AISI 304 in seawater is 0.2042 mpy belongs to the outstanding category. Meanwhile, the corrosion rate of St 37 in seawater is 27.0247 mpy belongs to the good category. It suggests that AISI 304 may be considered as an anchor chain to replace St37 for some reasons.

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