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**Galvanic Corrosion Assessment of ASTM A1010 Bridge Steel and Bolts and Effect of Temperature and Acidity**

Zhang, Jieying1,4, Ebrahimi, Nafiseh2, and Lai, David3

1,2National Research Council Canada, Construction Research Center, Canada

3 Ministry of Transportation Ontario, Toronto, ON, Canada

4 Jieying.Zhang@nrc-cnrc.gc.ca

**Abstract:** This study has compared the galvanic corrosion risk of two types of bolt for ASTM A1010 steel that is used in construction of a new generation of corrosion-resistant stele bridges. The high corrosion resistance of A1010 steel with a more positive corrosion potential imposes a risk of galvanic corrosion with the connection bolts in direct electrical contact. The galvanic corrosion was studied between A1010 steel and galvanized ASTM A325 Type I bolt and ASTM A193 B8 class 2 bolt, The result was compared to that of A325 bolt and weathering steel. Galvanic corrosion risk was evaluated through experimental investigation in the cells of aerated salt solution and was further validated by visual examinations of bolted steel plates in salt spray testing chamber. The effect of temperature and acidity of environments was also investigated to illustrate the impact of climate change. It shows that not only the galvanic corrosion risk of using B8 bolt in A1010 steel bridges is much smaller than that of A325 bolt, but also it is affected much less by temperature rise and increase in acidity. The study suggests that climate change may have very different effects on different components of a steel bridge, and effect on galvanic corrosion could be much worse than the individual components. Furthermore, the corrosivity of atmosphere for bridge design such as pollutants in an atmosphere and temperature rise needs to be reviewed and re-evaluated under climate change.

# Introduction

Weathering steel has been used in highway bridges in the U.S. since mid-60’s and in Ontario since 1968. Since the 1980s, Ministry of Transportation Ontario (MTO) has observed accelerated corrosion in weathering steel bridges at localized areas near leaking expansion joints and areas subjected to constant wetting, e.g. interior sections of box girders in some bridges and splice locations of plate girders. Since early 2000s de-bonding of corrosion products in layers over driving lanes of box girders has been observed, and it has been a potential safety concern and an on-going maintenance problem. After analyzing field samples, chlorides from de-icing salt was found to be the reason for the pre-mature corrosion damage of weathering steel (Coomarasamy et al. 2008).

MTO started a pilot project of using ASTM A1010 steel (ASTM 2013) for bridge constructions that aimed for much improved corrosion resistance in a chloride environment, but without requiring protective coating or regular maintenance during 75 years of service life. The composition of A1010 steel has about 10.5- 12.5 wt. % of chromium and its use has been instigated by the U.S. Federal Highway Administration (FHWA) (Virmani 2009). In 2002, FHWA funded to build the first demostration bridge using A1010 steel for a county road bridge in California. Oregon and Washington states in collaboration further investigated the feasibility of A1010 steel for longer span bridge girders. Oregon Department of Transportation (DOT) has built two A1010 steel girder bridges, and the first was opened to traffic in 2012 and the second one in 2013. Based on MTO’s recent lab evaluation as well as work by others, the corrosion resistance of A1010 steel could be greater than weathering steel by 10 times or more, and its atmospheric corrosion rate was shown to be even 74 times lower than that of weathering steel in an accelerated salt spray testing (Fletcher et al. 2006). It represents the third generations of steel bridge construction after the carbon steel bridge starting in the 1890s and weathering steel in 1960s in Canada and the U.S.

Construction of high corrosion-resistant bridges is of particular importance in a changing climate. Since 1950 the annual average surface air temperature over Canada’s landmass has warmed by 1.7°C, and average temperatures in Canada are expected to rise by an additional 1.5°C to 4.5°C by 2070, which is approximately twice the global average and Canada has, in general, become wetter in recent decades with an increase in annual precipitation of about 16% between 1950 and 2009 (Mekis and Vincent 2011). For steel bridges, the four environmental and atmospheric parameters that are the most critical for the corrosion loss of structural metals (ISO 9223, 2012) are: i) annual average air temperature; ii) average annual dry deposition of SO2; iii) average annual deposition of Cl-, and iv) average annual relative humidity. These four parameters become more aggressive for corrosion in a changing climate; for example, corrosion rate increases exponentially with increasing temperature following Arrhenius law so that corrosion rate of a metal can potentially double for every 10°C increase in temperature.

Climate change is a reality but design for corrosion protection of steel bridges is based on climatic data in the past. Canadian Highway Bridge Design Code (CHBDC) uses the concept of “corrosivity” to prescribe increasing levels of corrosion protection to metal components as the environmental exposure becomes severer. ISO 9223, 2012 is performance-based standard in which 7 levels of corrosivity are quantified through a first year corrosion rate of a metal. However, these corrosion rates used in ISO 9223 were based on world-wide field exposed specimens in the 1950s and 1960s, and current and future climate imposes a more corrosive environment. (Nguyen et al. 2013) used a modified Dose-Response Function model from ISO 9223 to quantify the climate change effect on the atmospheric corrosion rates of steel structures that considered the change in temperature, carbon dioxide, relative humidity, wind, rainfall and pollution. In the study two cities in Australia were considered and the highest emission projection was used. It predicted an average corrosion rate increase of 14% in 2100 for an inland city of Australia for both carbon steel and zinc, and 14% of increase in corrosion rate of steel in a coastal city.

On the other hand, using high corrosion-resistant steel requires a careful selection of connection bolts that have corrosion compatibility with the steel besides the sufficient mechanical properties. A great concern comes from galvanic corrosion that occurs between two different metals. A steel bridge girder and its connection bolts are in direct electrical contact after installation and exposed to the same electrolyte, which comes from rain, melting ice and snow, or a thin water film of condensation of air with salt spray. Therefore, a steel bridge girder and its connection bolts of a different metal can form a galvanic corrosion cell, where the one with a more negative corrosion potential, or more active (less noble) in a galvanic series, would be the anode and corrode preferentially (Jones 1992).

It is necessary to choose a bolt type that can be used in A1010 steel bridges with minimum risk of galvanic corrosion. We have investigated the galvanic corrosion of various bolts with A1010 steel (Zhang and Ebrahimi 2017, Ebrahimi et al. 2018) that can be used as the first corrosion research-based guidelines for choosing proper bolts for A1010 steel bridges. Among three types of bolt, namely, galvanized A325 type I bolt (A325 herein), and stainless steel bolt ASTM A320 B8 class 2 and A193 B6 stainless steel, B6 bolt was found to experience severe pitting corrosion in salt solutions and not recommended to be used in steel bridges. This study presents the galvanic corrosion of A325 bolts and B8 bolts with A1010 steel with an exploration of temperature and acidity effect under climate change.

# Experimental

The schematic galvanic corrosion cell formed between steel plate and bolt is illustrated in Figure 1 (a), where, the bolt normally serves as the anode and the steel plate the cathode. The galvanic corrosion experimental set up was schematically shown in Figure 1 (b), following the basic principles of ASTM G71 (ASTM G71 2014). The two samples, a structural steel and a bolt, were put in the sodium chloride (NaCl) containing solution, which was purged by air throughout the experiments, simulating the presence of moisture and air on a surface in atmospheric corrosion. They were connected through a zero resistance ammeter and their galvanic corrosion current (ICouple) and galvanic corrosion potential (ECouple) against standard calomel electrode (SCE) were monitored once the two samples were electrically connected. The polarity of the current measurement was set to be positive when the bolt sample was the anode in the galvanic corrosion.

All experiments were conducted using a Solartron 1287 potentiostat. Before and after coupling the two samples, their individual corrosion potentials ECORR and corrosion rate iCORR were also monitored (Ebrahimi et al. 2018). The structural steel samples were prepared with an exposed area of 10 cm2, while the bolt samples were prepared to have an exposed area of 1 cm2. When an area of moisture (electrolyte for corrosion to occur) covering both steel and bolt at a joint increases, the area ratio of structural steel/bolt for the galvanic corrosion increases, and a faster dissolution of the bolt, serving as an anode for the oxidation reaction, will be sustained by more reduction reactions that occur on the structural steel surface (Zhang and Ebrahimi 2017). The salt spray testing was also conducted on the above combinations of structural steel and bolts following the ASTM B117-16 procedure, in order to further validate the galvanic corrosion current measurement. The bolted samples were machined in 15 cm by 17 cm diameter plates, and two plates were then bolted together and tightened 1/3 turn after initial fastening of the bolts. In this test, the bolted plates are placed in a 5% salt spray and fog atmosphere for a certain period of time. Visual examinations were done after four weeks of exposure to compare the severity of the corrosion of the bolts.

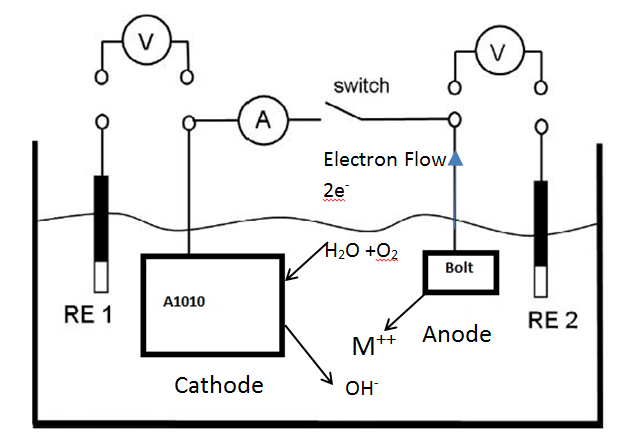
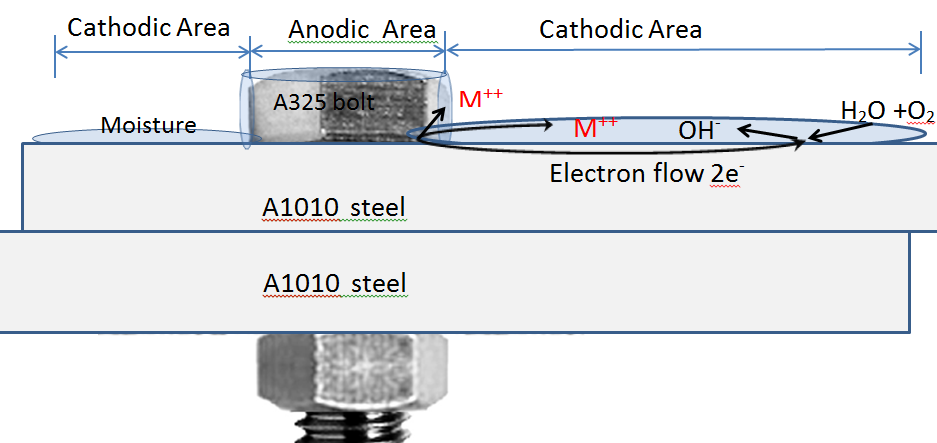


Figure 1**:**  Schematic drawing of a) galvanic corrosion cell of A1010 steel and A325 bolt; b) experimental setup

For the effects of temperature and acidity, three types of structural steel tested are A1010 steel, carbon steel, and A588 weathering steel, and two types of bolt material are A325 and B8. Their individual corrosion resistance was tested, and the galvanic corrosion current between A1010/ A325 was compared with A1010/B8. The testing was conducted under two temperatures and two levels of acidity to help understand further the corrosion resistance under climate change. A solution of NaCl with a concentration of 1.5 wt% was prepared using analytical grade NaCl crystals and deionized water, and a solution of 1.5 wt.% NaCl was prepared to have a pH value of 4.5 to simulate the acidic environment.

In summary, the experimental study is presented to measure the following corrosion behaviors:

1. Galvanic corrosion currents of the coupled A1010/A325, A1010/B8, and A588/A325 as a reference, at temperature of 25°C.
2. Validation of galvanic corrosion measurement by salt spray testing.
3. The individual corrosion potential rate of structural steel of A1010, A388, and carbon steel measured at two temperatures of 25 °C and 35°C
4. The individual corrosion potential rate of bolts of A325 and B8, and carbon steel measured at two temperatures of 25°C and 35°C
5. Galvanic corrosion currents of the coupled A1010/A325, A1010/B8, at a temperature of 35°C.
6. Galvanic corrosion currents of the coupled A1010/A325, A1010/B8, in an acidic solution of pH=4.5.

# Galvanic corrosion Assessment

A metal surface exhibits different corrosion potentials ECORR in different electrolytes or solutions, and the galvanic corrosion risks between two metals can be first inferred from by their ECORR difference. In all the modern engineering structures that frequently use mixed materials, the couplings of dissimilar metals are highly susceptible to galvanic corrosion, when their corrosion potential difference is more than 50 mV (Florain and Mansfeld 1971). Table 1 presents the average of ECORR of the samples in the NaCl solution of 1.5 wt. % measured in a period of 24 hours, and they provide the first indications of the galvanic corrosion rick between A1010 and the bolt samples. At 25°C, the ECORR difference between A1010/A325 is as high as about 800 mV, indicating a huge risk of galvanic corrosion for A325 bolt, because ECORR of A325 is more negative than A1010 which will make A325 an anode with accelerated metal dissolution. In contrast, the ECORR difference between A1010/B8 is less than 20 mV, indicating a negligible risk of galvanic corrosion for B8 bolts. The ECORR difference between A1010/A325 is also much greater than between A588/A325, and they are 800 mV versus 400 mV.

Table 1: Effect of temperature on corrosion behaviour of steels and bolts in 1.5 wt. % NaCl solution

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | A1010 Steel | | A325 Bolt | | B8 Bolt | | Carbon Steel | | A588 Steel | |
| Temperature | ECORR\* | ICORR\*\* | ECORR | ICORR | ECORR | ICORR | ECORR | ICORR | ECORR | ICORR |
| 25 °C | -230 | 0.67 | -1020 | 46 | -243 | 0.43 | -480 | 16 | -620 | 11.2 |
| 35 °C | -270 | 0.79 | -1040 | 75 | -235 | 0.37 | -550 | 26 | -630 | 20.6 |

ECORR\* (mV vs. SCE); ICORR\*\* (µA.cm-2)

The true galvanic corrosion risk, however, needs to be further evaluated through galvanic corrosion current measured between the metals, because the extent of galvanic activity is not always proportional to the difference in the ECORR of two metals. For example, the galvanic corrosion of zinc is the highest when coupled to steel than to most other metals such as Ni, Cu or Ti (Mansfeld et al. 1974), although the potential difference between zinc and steel, the driving force, is much less than between zinc and those metals. In atmospheric galvanic corrosion, other factors such as reaction kinetics and formation of corrosion products are also important in determining the galvanic corrosion rate. Figure 2 presents the measured galvanic corrosion potential ECouple and current between A1010/A325, A1010/B8, and A588/A325.

After two metals are put in electrical contact, their respective ECORR (Table 1) will shift to a common potential ECouple and reach a new equilibrium when the resistance of electrolyte is negligible. Figure 2(a) shows the common ECouple of the A1010/A325 couple is close to ECORR of A325, and similar to ECouple of the A588/A325. It implies that the galvanic corrosion currents between A1010/A325 and A588/A325 could be similar. This is confirmed by the current measurement shown in Figure 2(b) that the galvanic corrosion current is around 0.14 mA between A1010/A588, which is also similar to the average current between A588/A325.

The results show that the galvanic corrosion of galvanized A325 bolts Type I when used with A1010 steel can be similar to when they are used with A588 weathering steel, despite the corrosion potential differences being 800 mV and 500 mV, respectively, for the two combinations. This also shows that the corrosion potential difference, commonly found in a galvanic series (Jones 1992) of two metals can be used as a general guide to assess the galvanic risk, but the galvanic corrosion rate is not necessarily proportional and needs to be determined experimentally.

Figure 2: Galvanic corrosion potential (a) and coupling current (b) of A1010/A325, A588/A325, and A1010/B8

Examining the current ICouple measured between A1010/A325 and A588/A325 more closely, it shows fluctuation with time reflecting the dynamic corrosion process. Considering the surface area of A325, the corresponding corrosion rate of A325 by galvanic corrosion is between 180 to 280 µA/cm2. As compared with the individual corrosion rate of A325 (Table 1), i.e. 46 µA/cm2 in 0.1 wt. % NaCl solution, the galvanic corrosion with A588 has made the zinc coating of A325 corrode away 4 to 6 times faster during the measurement time of 24 hours. This means that galvanic corrosion could accelerate the dissolution of zinc and shorten the protection time provided by zinc layer significantly. On the other hand, Figure 2(b) the coupling current between A1010/B8 is as low as 1 µA/cm2.

Figure 3 shows that after four weeks of the salt spray test, A325 bolts when used with either A588 weathering steel or A1010 steel have corroded heavily in the accelerated corrosion environment, while two B8 bolts showed almost no sign of corrosion. It is consistent with the conclusion drawn from the measured galvanic corrosion currents.

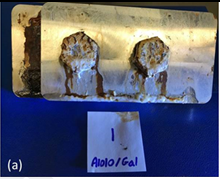
  

Figure 3: Visual of bolts with steel plate after four weeks of salt spry test of (a) A588/A325; (b) A1010/A325; and (c) A1010/B8

From the above results, it implies that if A325 bolts are used in A1010 steel bridges, similar protection measures for weathering steel bridges shall be applied to, e.g. coating of A1010 steel at an overlapping joint to reduce the cathodic area, which would, however, defy one of the reasons of constructing A1010 steel bridges. Using B8 bolts is found to have a negligible galvanic corrosion risk with A1010 steel. It is important to note that this project focused the galvanic corrosion risk of A1010 steel and bolts, and it did not include other types of corrosion and corrosion risks; for example, the stress corrosion cracking risk of using stainless steel bolts that are in a chloride-laden environment and bear a high tensile stress is not studied.

# Temperature and Acidity effect

Based on world-wide field exposed specimens of 20 years in the 1950s and 1960s, ISO 9223 (2012) considers four environmental and atmospheric parameters to be the most critical for the corrosion loss of structural metals (carbon steel, zinc, copper and aluminum) after the first year of exposure (*rcorr*).

1. average annual dry deposition of SO2, *Pd* (mg/m2.d)
2. average annual deposition of Cl-, *Sd* (mg/m2.d)
3. annual average air temperature, T (oC)
4. average annual relative humidity, RH (%)

For example, the first year corrosion rate of carbon steel is the function of the above parameters by the Dose-Response Function (DRF) model as follows:

[1] *rcorr*= 1.77*Pd*0.52 exp(0.02RH+*f*St)+ 0.102*Sd*0.62 exp(0.033RH+0.04T)

Where *f*St is given by: for T ≤ 10oC , *f*St =0.15T-10 T > 10oC , *f*St =0.054T-10

The DRF of ISO 9223 is the model widely adopted throughout for classifying the corrosivity of an atmosphere based on the first year of corrosion loss by the measurements of [time of wetness](http://www.corrosion-doctors.org/AtmCorros/TOW.htm), and pollution categories ([sulfur dioxide](http://www.corrosion-doctors.org/AtmCorros/sulfur-diox.htm), [airborne chlorides](http://www.corrosion-doctors.org/AtmCorros/chlorides.htm)). Based on these measures an atmosphere is classified as being in one of six categories in terms of its corrosivity of the first year corrosion rate (*rcorr*) of steel as g.m-2.year-1 (one year). The longer term corrosion loss (*D*) of structural metals was found to be usually linear with exposed time on logarithmic coordinates as follows (ISO 9224 2012).

[2] *D=rcorr t b*

Where *t* is the exposure time in years, *b* is the metal-environment-specific exponent usually less than 1. It suggests that the atmospheric corrosion of A1010 steel needs to be understood further for durability design, as well as the galvanic corrosion of connecting bolts used in A1010 steel bridges, particularly in a changing climate.

## Temperature effect

To explore the effect of temperature on the corrosion behaviour of alloys, an elevated temperature of 35°C was selected. The corrosion cell was immersed in a hot water bath and the temperature was controlled by a hot plate. Table 1 presents the corrosion potential ECORR and corrosion rate ICORR, of the three structural steels and two bolt materials, and all samples show a slight decrease in ECORR by increasing the temperature from 25°C to 35°C. A1010 steel shows 40 mV drops in ECORR, A325 by 20 mV, carbon steel by 70 mV and weathering steel by 10 mV. Corrosion rates, on the other hand, have shown a significant increase on A325, A588, and carbon steel by 63%, 82% and 62%, respectively. The results are close to the estimation by a rule of thumb that the corrosion rate of a metal may double for every 10°C increase in temperature.

By contrast, corrosion rate of A1010 steel increases slightly from 0.67 µA/cm2 to 0.79 µA/cm2 (about 17 % of increase), and B8 bolt has even actually showed a slight decrease in corrosion rate. The reason for their different response to temperature is probably due to more rapid passive oxide film formation at a higher temperature. It should be noted however, the observed beneficial effect may be limited to this range of temperature and further increasing the temperature may lead to an adverse effect as the passive film will become unstable at a higher critical temperature (like critical pitting temperature or critical crevice temperature). It shows within the temperature range from 25°C to 35°C, both A1010 steel and B8 bolt show much more resistance to corrosion attack by temperature rise.

The impact of a raised temperature by 10°C from 25°C therefore, result in a range of increases in corrosion rate from 17% to 82%, depending on the type of metal and bolts. This implies that corrosion of structural metals and bolts for bridges and building need to be evaluated individually under climate change, especially the critical structural components.

Figure 3(a) shows the galvanic corrosion currents ICouple of A1010/A325 measured at 25°C and 35°C**.** For A1010/A325 couple, the initial ICouple increases from 0.3 mA to 0.8 mA by raising the temperature from 25°C to 35°C, almost 3 times higher. Compared with their individual corrosion resistances as discussed above where the corrosion rate of A325 by itself is increased by about 65% and A1010 even less, the galvanic corrosion is more affected by temperature rise.

By comparing their ECORR at 25**°**C to 35**°**C (Table 1), A1010 has slightly more positive potential than B8 which makes it a cathode in the galvanic corrosion. As temperature rises to 35**°**C, ECORR of A1010 becomes more negative than that of B8, and would become an anode to B8 when coupled. This is confirmed by the galvanic current measurements as shown in Figure 3 (b) that shows the current has shift polarity when temperature rises from 25**°**C and 35**°**C from 1 μA to -1.5 μA, which are both much smaller than ICouple of A1010/A325 by more than two order of magnitude. The galvanic corrosion risk of using B8 is not only much smaller than using A325 in A1010 bridges but also is affected much less by temperature rise.

Figure 4: ICouple of A1010/A325 (a) and A1010/B8 (b) at 25°C and 35°C

## Acidity Effect

Rain water is naturally (slightly) acidic because carbon dioxide gas in the atmosphere reacts with water to form carbonic acid, but sulfur oxide (SO2) and nitrogen oxide (NOx) molecules that result from industrial pollution and automobile exhaust get into the air and react with water to form strong acids. Acid rain can have a pH of less than 5.6, and industrial areas have been reported to have acid rain that is below a pH of 2.4 (Singh and Madhoolika 2007).

In this study, only effect of pH in acidic rain was investigated using a 1.5 wt. % NaCl solution containing 31.85 mg/L Sulphuric acid (96%) and 15.75 mg/L Nitric acid (15.75) with final pH of 4.5. The individual corrosion performances of A1010, A325 and, B8 alloys at neutral pH and pH 4.5 in the 1.5 wt. % NaCl solution is summarized in Table 2.

Table 2: Individual corrosion performances of A1010, A325 and,B8 alloys at neutral pH and pH 4.5

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | A1010 Steel | | A325 Bolt | | B8 Bolt | |
| pH | ECORR\* | ICORR\*\* | ECORR | ICORR | ECORR | ICORR |
| 7 | -230 | 0.67 | -1020 | 46 | -243 | 0.43 |
| 4.5 | -219 | 4.15 | -1010 | 92 | -260 | 0.47 |

Figure 4(a) presents the galvanic corrosion current of A1010/A325 at pH 7 and pH 4.5, which shows that it increases by 4 times initially and down to 2 times within first 24 hours when acidity is increased. The increase is in the order of 500 uA. Figure 4(b) shows ICouple of A1010/B8 has a shift in the polarity from 1 μA to -5 μA when pH is decreased to 4.5. Compared with A1010/A325, A1010/B8 still has a much smaller galvanic corrosion current by about two orders of magnitude. This behaviour by increasing acidity is similar to that observed by raising temperature, in that the galvanic corrosion risk of using B8 is not only much smaller than using A325 in A1010 bridges but also affected much less by acidity.

Figure 5: ICouple of A1010/A325 (a) and A1010/B8 (b) in solutions of pH 7 and pH 4.5

This preliminary experimental study implies that climate change may have very different effects on different components of a steel bridge, and effect on galvanic corrosion could be much worse than the individual components. This makes the service life prediction of components and a bridge system even more challenging and calls for further study for better understanding. Furthermore, the corrosivity of atmosphere for bridge design needs to be reviewed and re-evaluated under climate change that can result in change of atmospheric pollutants’ concentration in addition to the temperature rise and change of the acidity of the rain.

# Summary and DisCussion

The galvanic corrosion of galvanized A325 bolts Type I bolts when used with A1010 steel can be similar to when they are used with A588 weathering steel, despite the corrosion potential differences being 800 mV and 500 mV, respectively for the two combinations. This indicates that the corrosion potential difference, commonly found in a galvanic series of two metals can be used as a general guide to assess the galvanic risk, but the galvanic corrosion rate is not necessarily proportional and needs to be determined experimentally. It implies that if A325 bolts are used in A1010 steel bridges, similar protection measures of weathering steel bridges shall be applied, e.g. coating of A1010 steel at an overlapping joint to reduce the cathodic area, which would, however, defy one of the reasons of constructing A1010 steel bridges.

Using B8 bolts is found to have a negligible galvanic corrosion risk with A1010 steel. It is important to note that this project focused on the galvanic corrosion risk of A1010 steel and bolts, and it did not include other types of corrosion and corrosion risks; for example, the stress corrosion cracking risk of using stainless steel bolts that are in a chloride-laden environment and bear a high tensile stress was not studied.

Corrosion rates of A1010 in a NaCl solution of 1.5 wt% are found to be much smaller than carbon steel and weathering steel, and corrosion rate of B8 bolt much smaller than A325 bolt. The preliminary study of temperature rise from 25°C to 35°C shows that corrosion rates of A1010 and B8 bolt have shown much resistance to temperature rise too. On the other hand, the temperature rise of 10°C has induced significant increase on A325, A588, and carbon steel by 63%, 82% and, 62%, respectively. It should be noted however, the observed beneficial effect may be limited to this range of temperature and further increasing the temperature may lead to an adverse effect as the passive film will become unstable at a higher critical temperature which calls for further study.

Compared with their individual corrosion resistances, the galvanic corrosion is more affected by temperature rise. This makes the service life prediction of components and a bridge system even more challenging. This calls for further investigation for better service life prediction. The galvanic corrosion risk of using B8 is not only much smaller than using A325 in A1010 bridges, but also affected much less by temperature rise and increase in acidity.

In summary, the study shows that A1010 steel bridges have much higher corrosion resistance and more resistance to climate change, and using stainless steel B8 bolts has negligible galvanic corrosion risk. The preliminary study of temperature and acidity effect suggests that the design corrosivity of atmosphere of a bridge needs to be reviewed and re-evaluated under climate change such as pollutants in an atmosphere in addition to the temperature rise.

This preliminary experimental study implies that climate change may have very different effects on different components of a steel bridge, and effect on galvanic corrosion could be much worse than the individual components. This makes the service life prediction of components and a bridge system even more challenging and calls for further study for better understanding. Furthermore, the design corrosivity of atmosphere of a bridge needs to be reviewed and re-evaluated under climate change such as pollutants in the atmosphere in addition to the temperature rise.

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