Chapter III

SLOW STRAIN RATE TENSILE MACHINE

3.1 Introduction

The slow strain rate tensile (SSRT) testing has now been widely used to evaluate the degree of sensitization of 304 stainless steels. It was chosen mainly because it is relatively severe and is particularly good at initiating crack. This chapter begins with the description of the SSRT testing machine developed to use in this thesis. The calibration of the extension rate of the SSRT unit is tested. Type AISI 304 austenitic stainless steel donated by Thainox Steel Limited is used to test the performance of the machine. The test begins with the determination of the characteristic curve of the stainless steel, yield strength, and modulus of elasticity (Young's modulus) were calculated and compared with that given in the literature. The details of the chemical cell needed to provide aggressive environments for tensile testing are also described in this chapter.

3.2 Slow Strain Rate Tensile Testing Machine

It is well known that the level of stress corrosion cracking susceptibility in austenitic stainless steel specimens with varying degree of sensitization can be determined using slow strain rate tensile (SSRT) testing. The SSRT testing machine is design to perform test in hazardous environment at a very low strain rate ($< 1 \times 10^{-5}$ per second). The SSRT unit consists of a motor driven pulled rod with a load cell and linear variable differential transformer (LVDT) to measure the loads and extension on the specimens continuously as shown in figure 3.1.

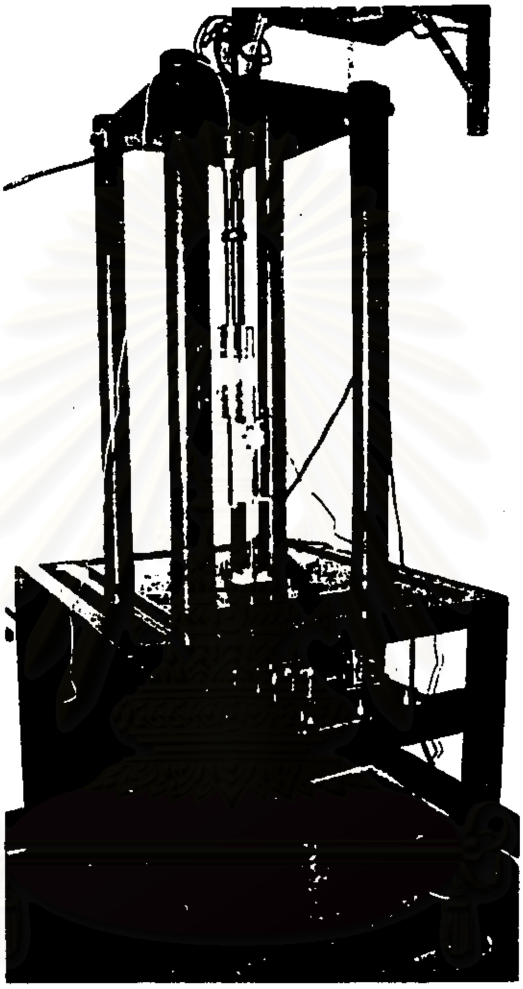

Figure 3.1 Illustration of the slow strain rate tensile machine used in this thesis.

The load frame of the SSRT is entirely made of carbon steel. The upper pulled rod is threaded and fixed to the upper load frame while the lower pulled rod is attached to a 5:1 ratio lead screw driven by a reduced gear box with a ratio of 1:3,600 (consisting of 2 reduced gear box with a ratio of 1:60) providing a very low extension rate capable of travelling in both upward and downward direction for compression and tension test, respectively. The gearbox is powered by a ¼ HP motor capable of adjusting speed from 0-41 rpm. A 1000-lb (454.55-kg) miniature load cell obtained from Transducer Technique is attached to the upper pulled rod for measuring load response of deforming specimens. An OMEGA linear variable differential transformer type transducer is employed for extension measurement. The LVDT is mounted onto a ball-bearing guide rod attached to the lower pulled rod providing frictionless motion for accurate extension measurement. Figure 3.2 shows the load train of the SSRT machine with failure specimen. The detail description and engineering drawing of the SSRT testing machine used in this thesis is illustrated in appendix I.

3.3 The Extension Rate

The lower pulled rod attached to a worm screw driver has the pitch of 3/16-inch (4.7625-mm.) with a reduced gear ratio of 1:5. A reduced gearbox with a total ratio of 1:3,600 is used to drive the lead screw. A total reduced gear ratio of 1:18,000 is thus expected. The whole gearing system when attached to a ¼ HP motor 0-41 rpm provides a very low extension rate and can be calculated as follows:

$$\text{Extension rate} = \left(\frac{R}{18000}\right) \times P \qquad \frac{\text{mm.}}{\text{min.}} \qquad (3.1)$$

$$= \left(\frac{R}{18000}\right) \times \left(\frac{P}{60}\right) \qquad \frac{\text{mm.}}{\text{sec.}} \qquad (3.2)$$

Where R = revolution of motor in rpm

P = pitch of the lead screw in mm.

The revolution of the powered motor can be varied from 0-41 rpm by adjusting the speed controller knob by position from 0-11. The relationship between the position of speed controller knob and the revolution of powered motor is shown in table 3.1. Thus, by varying the speed of powered motor from 0-41 rpm, a very low extension rate from about of 3×10^{-5} mm. per second to 1.8×10^{-4} mm. per second is expected. The calibration of the extension rate as a function of the speed controller (by position) is shown in figure 3.3.

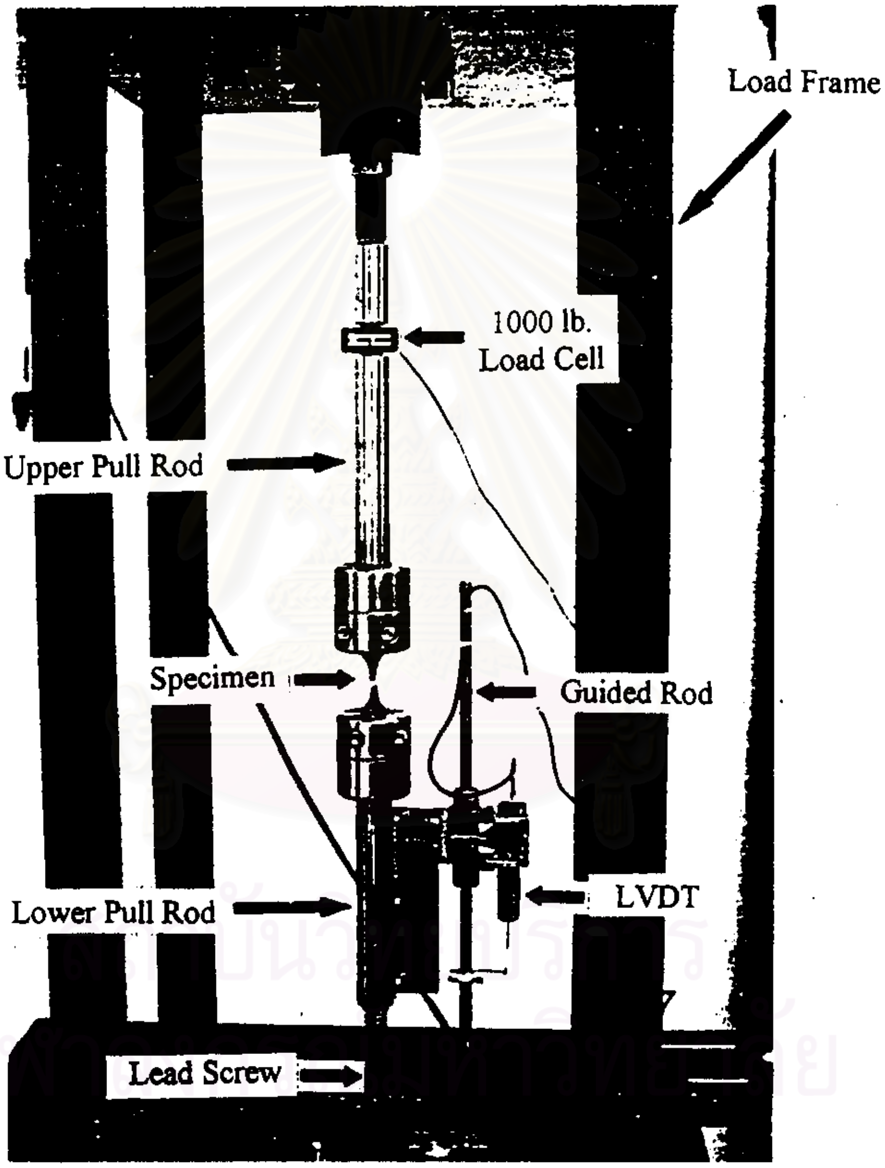

Figure 3.2 Illustration of the load train of the slow strain rate tensile machine with failure specimens.

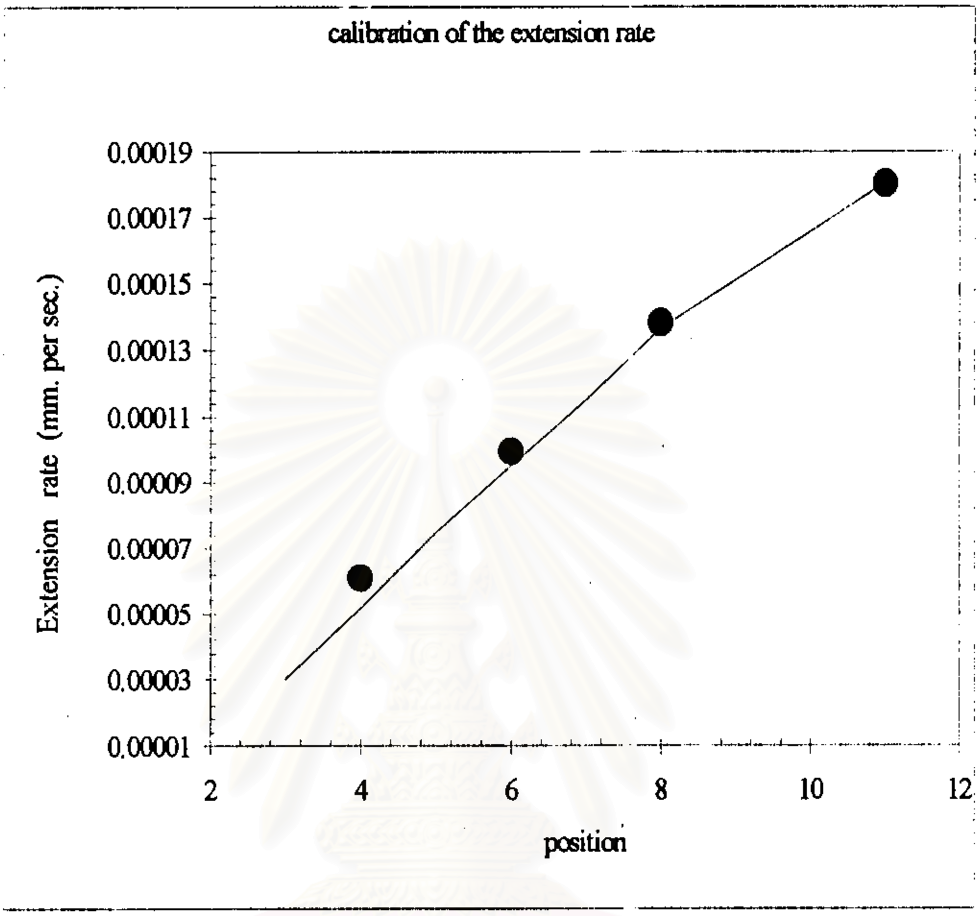

Figure 3.3 Shows the calibration curve of the extension rate.

According to figure 3.3, it clear that the extension rate obtained from the calculation is similar to the extension rate obtained from the measurement. It was found that the highest rate of this SSRT is 1.8 × 10^{-4} mm per second at position 11 and the lowest is 6.06596 × 10^{-5} mm per second at position 4. Below the speed set point 3, the motor is no longer responding.

Table 3.1 The relationship between the position of speed controller knob and speed of powered motor.

Position of speed controller knob	The revolution of motor (rpm)	The expected extension rate (mm per second)	The extension rate obtained from measurement (mm per second)
1	0	0	*
3	6.8	3.00×10^{-5}	*
4	11.7	5.16×10^{-5}	6.07×10^{-5}
5	16.9	7.45×10^{-5}	*
6	21.6	1.53×10^{-5}	9.94×10^{-5}
7	26.1	1.15×10^{-4}	*
8	30.9	1.36×10^{-4}	1.38×10^{-4}
11	41.0	1.80×10^{-4}	1.80×10^{-4}

* not observed

3.4 The stiffness of the SSRT unit

The stiffness of the tensile machine is important in quantifying mechanical properties of the materials. Soft tensile machine can introduce errors in load determination of the specimen. The stiffness of the SSRT machine can be determined by investigating elastic property of a deformed specimen using the SSRT. The typical characteristic stress-vs-strain curve of the type 304 stainless steel obtained from the SSRT machine is shown in figure 3.4.

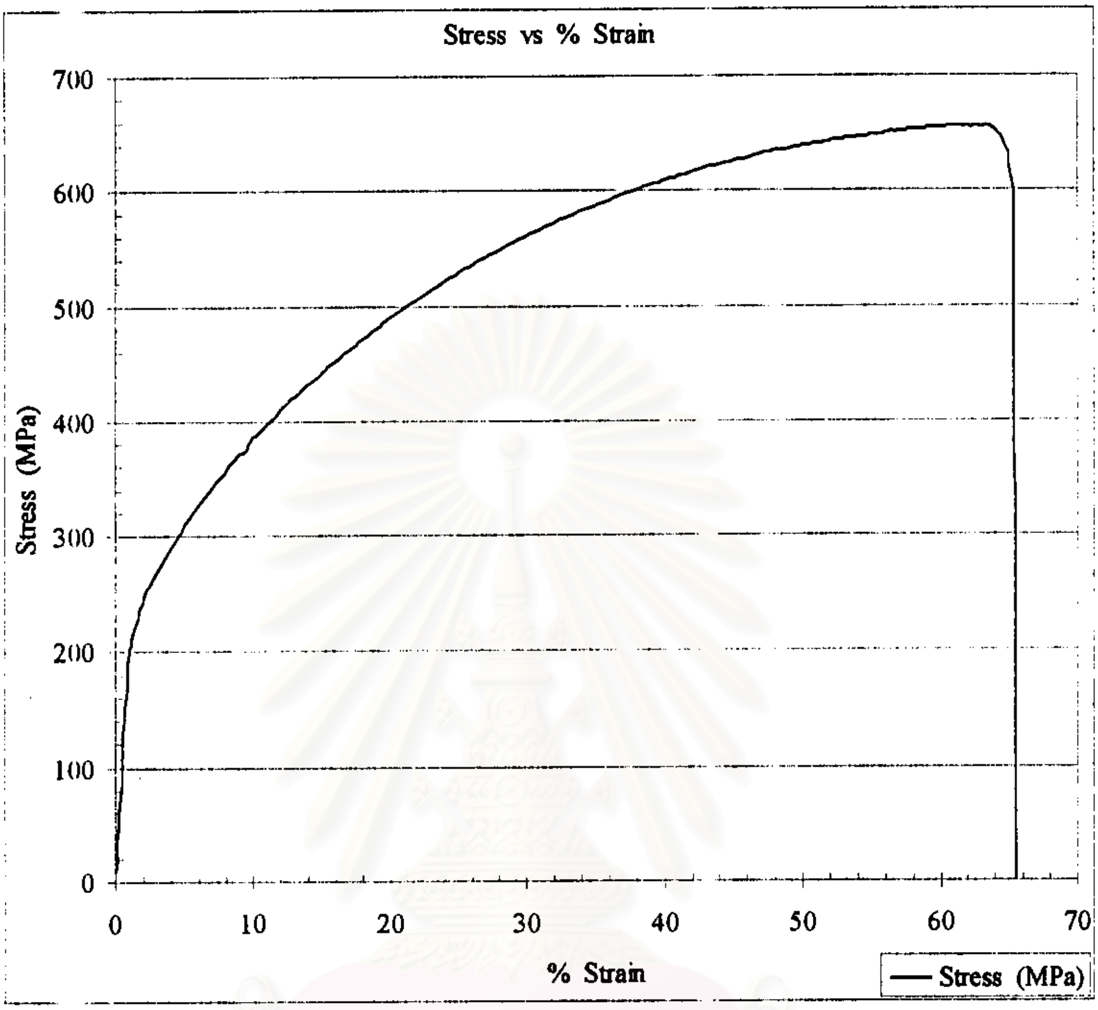

Figure 3.4 Illustration of the characteristic stress-vs-strain curve of type 304 stainless steel.

To calculate the modulus of elasticity, the low deformation region of type 304 stainless steel was plotted as shown in figure 3.5. From figure 3.5, we can determined the Young's modulus (E), which is the ratio of the engineering stress (σ) and engineering strain (ε) in elastic deformation region, and can be calculated as follows:

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} \quad \text{GPa.} \tag{3.3}$$

From figure 3.5

$$
\begin{aligned}
E &= \frac{(193.25 - 95.36)}{(0.0130 - 0.0065)} \quad \text{MPa} \\
&= 15060 \quad \text{MPa} \\
&= 15.06 \quad \text{Gpa}
\end{aligned}
$$

The yield strength, which is the engineering stress at 0.2% elongation and can determined to be 270-MPa as shown in figure 3.5. Table 3.2 shows the value of physical characteristic of the stainless steel obtained from the machine compare to the value obtained form the factory.

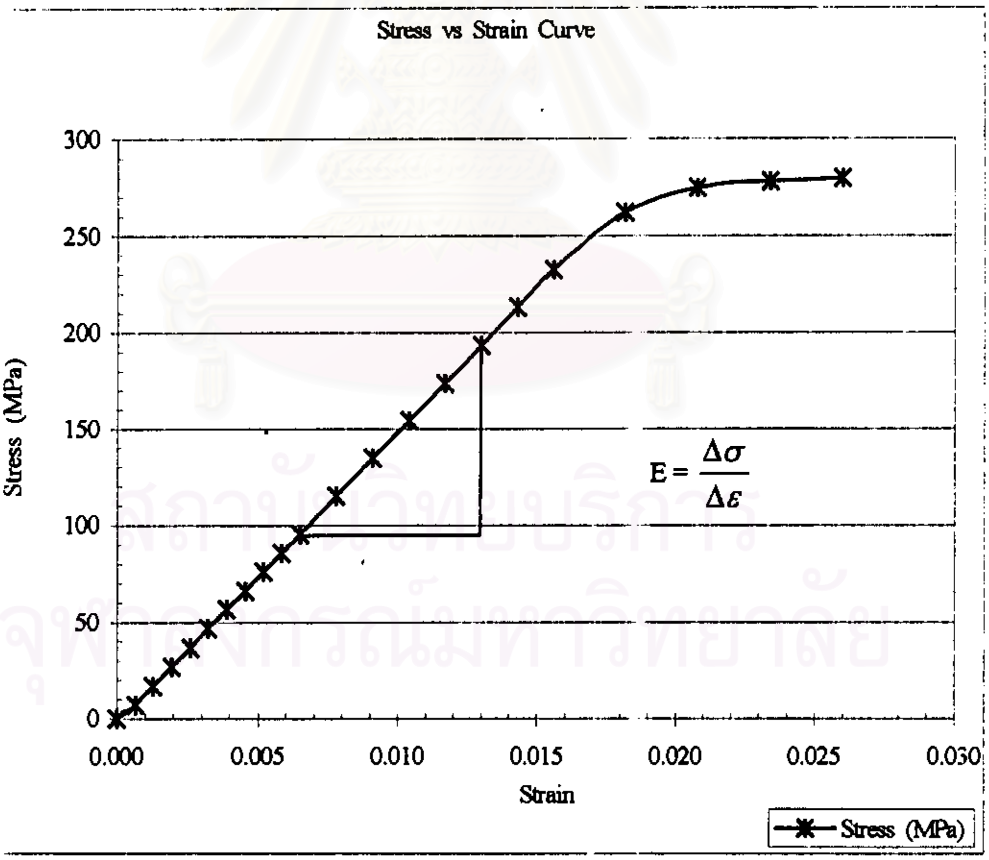

Figure 3.5 Illustration of the low deformation region of type 304 stainless steel.

According to table 3.2 it was found that all physical characteristics obtained from the machine has been differ from the factory mainly because of the load train dose not have enough stiffness. Thus, they may extend during the tests; as a result, the loading output and/or strain in the specimen is slightly incorrect. From table 3.2, we found that the modulus of elasticity obtained from SSRT machine is tiny differ from the value obtained from the report. Therefore, it may be assumed that the error in the stress-vs-strain curve occurs from the strain output. While compare to the ideal stress-vs-strain curve obtained from the factory figure 3.6.

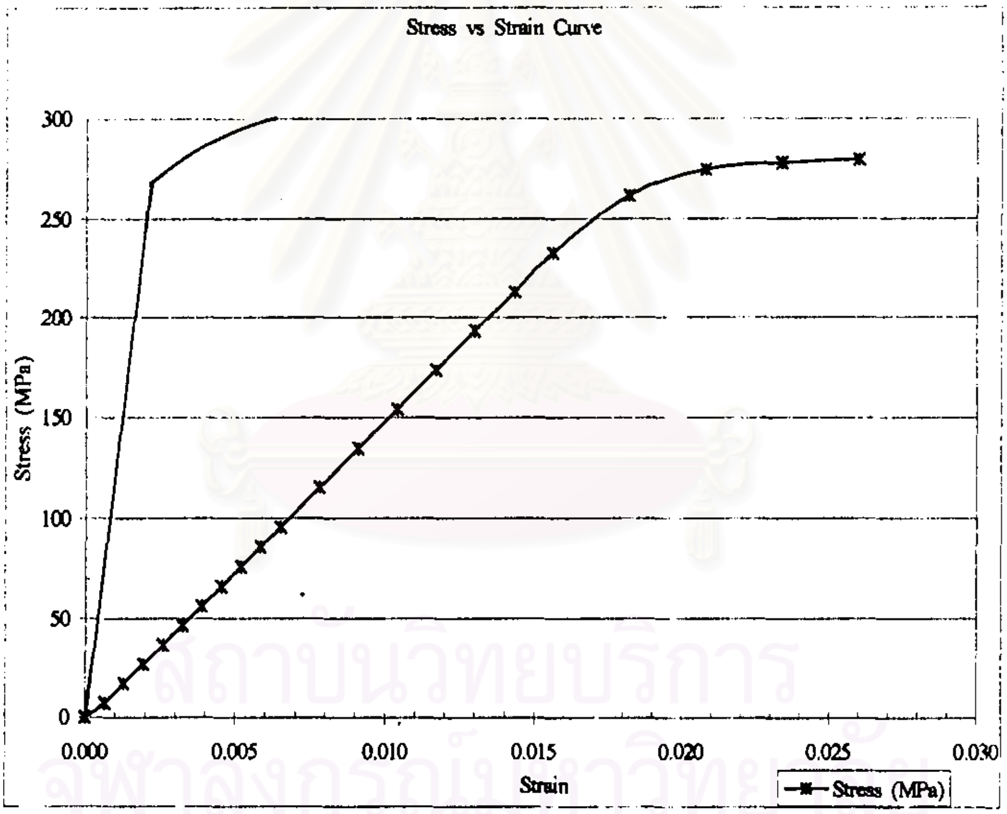

Figure 3.6 Illustration of the low deformation region of type 304 stainless steel obtained from the report and SSRT machine.

From figure 3.6, we can determine the error in strain out put by equation 3.4. As a result, it found that the error in strain output is about of 300 micrometer. Although, a miniature load cell can introduce errors, a larger load cell may not be the best choice. In general, the accuracy of load cell depends on the maximum load. If the load is small compared to its maximum capability, the accuracy of the load cell will decrease. In our experiment, we employed a 1000-lbf miniature load cell and the UTS of the test specimens were in order of 950-lbf. Furthermore, in our study we only compare the relative effects of maximum load of specimens with different microstructures of the specimens. Thus, a miniature load cell is qualified for this study.

Table 3.2 Comparison of the physical characteristics of type 304 stainless steel obtained from the measurement and factory's report.

Physical characteristic	Factory's report	Obtained from SSRT machine
Modulus of elasticity (Young's modulus) (MPa)	193	15.06
Yield's strength (0.2% elongation) (MPa)	300	270

3.5 Chemical cell

The particularly advantage of SSRT technique for evaluating the degree of sensitization over other technique is the variable strain rate and it can be used in varying corrosive environment thus, the chemical cell has been proposed. The chemical cell used in this experiment made from a 2-mm. thick acrylic sheet. The dimension is 8-cm wide, 8-cm long and 7-cm tall, figure AI.7. A volume of 340-ml of solution can be filled in and used for this work.

Thiosulfate solution is used to provide an aggressive environment in this study. An analytical grade sodium thiosulfate pentahydrate ($Na_2S_2O_3.5H_2O$) obtained from Fluka Chemika was used. A 0.5-M $Na_2S_2O_3.H_2O$ was used and the calculation is shown below.

Volume of the cell = 340 ml

A 0.5-M $Na_2S_2O_3.H_2O$ means 0.5 mole in 1000 ml.

$$\text{Thus, we need} = \frac{(340\,\text{ml}) \times (0.5\,\text{mole})}{1000\,\text{ml}} \quad \text{mole}$$

$$= 0.17 \quad \text{mole for this chemical cell.}$$

Since the molecular weight of $Na_2S_2O_3.H_2O$

$$= (23 \times 2) + (32 \times 2) + (16 \times 3) + 5 \times \{(2 \times 1) + 16)\}$$

$$= 248.00 \quad \text{g}$$

The concentration 0.17 mole = 0.17×248.00 = 42.16 g.

It should be noted that for every mole of $Na_2S_2O_3.H_2O$, there are

1 mole of $Na_2S_2O_3$

and 5 mole of H_2O

Thus 0.17 mole of $Na_2S_2O_3.H_2O$ contains only 0.17 mole of $Na_2S_2O_3$. The volume of distilled water = 340 ml equivalent to

$$= (340\ \mathrm{cm}^3) \times (\frac{1\mathrm{mole}}{18\ \mathrm{g}}) \times (\frac{1g}{\mathrm{cm}^3})$$

$$= 18.88\ \mathrm{mole}$$

Thus the concentration of $Na_2S_2O_3$ in the water is equal to

$$= \frac{0.17}{18.88}$$

$$= 9.00 \times 10^{-3}$$

$$\cong 9000\ \mathrm{ppm\ of}\ Na_2S_2O_3$$

$$= 0.9\ \%\ Na_2S_2O_3$$