CHAPTER 1
INTRODUCTION

1.1 Background of Study

The function of a radiator is to cool the liquid coolant. Air flowing through the radiator carries away heat and lowers the temperature of the coolant by a hundred degrees or more.

For efficient cooling, the radiator must be in good condition and receive adequate air flow. The radiator's front-mounted location ensures good air flow when the vehicle is in motion, but at low speeds and when the vehicle is stopped, a cooling fan must be used to boost air flow.

Radiators can usually go eight to ten years or more without requiring any repairs. But the most common cause of radiator failure is internal corrosion caused by coolant neglect. If the coolant isn't changed at the recommended service intervals, it may become acidic and attack the radiator and other components.[9]

The average amount of time for replacing the coolant is between one and two years because the additives wear out and become corrosive. The coolant, usually a 1:1 mixture of antifreeze (ethylene glycol) and water is used in the cooling system of the automobile.

According to K K Jain, R B Asthana, 2002, the long-term reliability and cooling capacity of the engine cooling system depends much on the quality of the cooling water used. Use of hard water and water high in acid concentration will foul up the cooling circuit by scale formation and also promote rusting. For such reasons river water, well water and sea water is not fit to be used as an engine coolant. Distilled water is ideal for the cooling system, but is a luxury in most cases (pg 57).

1.2 Problem Statement

After several years of service, the radiator system of a Kancil car is experienced leaking on its steel pipe. On the early stage of its failure the owner of the car found that the level of radiator coolant has decreased prematurely and the engine temperature increase higher than normal. Regardless of the problem, the owner just filled up the radiator tank with water.

Nevertheless the period of the coolant decrease became shorter and the owner of the car faced many problems due to high engine temperature. The owner decided to go to workshop to solve this problem. After the inspection, they found the pipe of the radiator experienced a major leakage and the pipe was replaced with a new pipe.

In view of the premature steel pipe failure, it is imperative to investigate the cause of the failure for future action and recommendation.

1.3 Objective and Scope of Study

1.3.1 Objective

1. To investigate the cause and the mode of pipe failure.
2. To recommend ways to improve the service life of radiator pipe as well as the radiator system.

1.3.2 Scope of Study

1. The investigation using nondestructive examination method (NDE).
2. Application of failure analysis technique to examine the chemical properties and mechanical properties of the steel pipe.

CHAPTER 2
THEORY AND LITERATURE REVIEW

2.1 Theory

2.1.1 Cooling System

The cooling systems control the engine temperature by dissipating heat into the atmospheric. About 30% of heat is lost by the cooling system and only 10% of heat is lost by radiation. About 25% to 30% of heat is used to perform work. The rest of the heat is lost through the exhaust gases and the cooling medium.

2.1.2 Water Cooling

The water cooling system is an indirect cooling system. Water is cheap and easily available. Its specific heat being greater than that of air, water can absorb more heat than air. Water absorbs heat and dissipates it into the atmospheric air. Therefore, the same water can be circulated by a pump and used again.

Water is forced by a water pump in the water jacket of the engine. Hot water comes out from the jacket of the engine and is passed into the radiator. The vertical radiator tubes are brought in contact with the atmospheric air. Water passing through these tubes gets cooled and is collected at the bottom of the radiator. The water pump re-circulates water through the water jacket of the engine.

There is also a fan which is driven by the engine of electrically as in a modern car. The fan draws air and blows it over the engine parts. This the partial vacuum created behind the radiator, increases the pressure difference across the radiator and more air flows through the narrow gaps between the radiator tubes. Thus the quality of air passing through the radiator is increased. This air drawn by the fan is blown over the engine body and the engine temperature is reduced.

The forced circulation of water does not allow its temperature to rise to the boiling point. Scale formation takes place in boiling water. Scales are the deposits of salts and mud and are a bad conductor of heat. Therefore, scale deposition leaves hot spots in the combustion chamber which may lead to detonation and pre-ignition in a petrol engine. Hence, forced circulation of water is essential in the engines (K K Jain, R B Asthana, 2002).

2.1.3 Radiator

A radiator is a device which is used as a heat exchanger between the hot water and atmospheric air. Radiators are essentially used in heavy duty automobiles for cooling the automobile engines. Water, which is forced by a pump into the water jacket of the automobile engine, is sent to the radiator, from where water is passed through the tubes of the radiator which dispel the heat to the air which flows round the tubes. Thus a radiator is a device which permits the cooling of water through the transfer of heat to the atmospheric air.

2.1.4 Welding Defects [11]

Common weld defects include:

- i. Lack of fusion
- ii. Lack of penetration or excess penetration
- iii. Porosity
- iv. Inclusions
- v. Cracking
- vi. Undercut
- vii. Lamellar tearing

Any of these defects are potentially disastrous as they can all give rise to high stress intensities which may result in sudden unexpected failure below the design load or in the case of cyclic loading, failure after fewer load cycles than predicted.

Types of Defects

i Lack of fusion. - To achieve a good quality join it is essential that the fusion zone extends the full thickness of the sheets being joined. Thin sheet material can be joined with a single pass and a clean square edge will be a satisfactory basis for a join. However thicker material will normally need edges cut at a V angle and may need several passes to fill the V with weld metal. Where both sides are accessible one or more passes may be made along the reverse side to ensure the joint extends the full thickness of the metal.

Lack of fusion results from too little heat input and / or too rapid traverse of the welding torch (gas or electric). Excess penetration arises from to high a heat input and or too slow transverse of the welding torch (gas or electric). Excess penetration - burning through - is more of a problem with thin sheet as a higher level of skill is needed to balance heat input and torch traverse when welding thin metal.

ii. Porosity - This occurs when gases are trapped in the solidifying weld metal. These may arise from damp consumables or metal or, from dirt, particularly oil or grease, on the metal in the vicinity of the weld. This can be avoided by ensuring all consumables are stored in dry conditions and work is carefully cleaned and degreased prior to welding.

iv. Inclusions - These can occur when several runs are made along a V join when joining thick plate using flux cored or flux coated rods and the slag covering a run is not totally removed after every run before the following run.

v. Cracking - This can occur due just to thermal shrinkage or due to a combination of strain accompanying phase change and thermal shrinkage.
In the case of welded stiff frames, a combination of poor design and inappropriate procedure may result in high residual stresses and cracking.
Where alloy steels or steels with a carbon content greater than about 0.2% are being

welded, self cooling may be rapid enough to cause some (brittle) martensite to form. This will easily develop cracks.

To prevent these problems, a process of pre-heating in stages may be needed and after welding a slow controlled post cooling in stages will be required. This can greatly increase the cost of welded joins, but for high strength steels, such as those used in petrochemical plant and piping, there may well be no alternative.

Solidification Cracking

This is also called centerline or hot cracking. They are called hot cracks because they occur immediately after welds are completed and sometimes while the welds are being made. These defects, which are often caused by sulphur and phosphorus, are more likely to occur in higher carbon steels. The location of centerline crack is as shown in Figure 2.1.

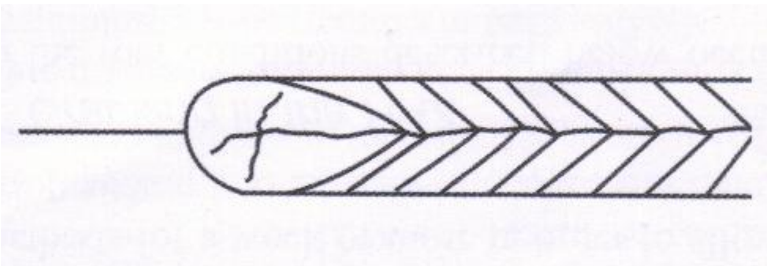

Figure 2.1: A schematic diagram of a centerline crack

Solidification cracks are normally distinguishable from other types of cracks by the following features:

- they occur only in the weld metal - although the parent metal is almost always the source of the low melting point contaminants associated with the cracking
- they normally appear in straight lines along the centerline of the weld bead, but may occasionally appear as transverse cracking
- solidification cracks in the final crater may have a branching appearance
- as the cracks are 'open' they are visible to the naked eye

On breaking open the weld the crack surface may have a blue appearance, showing the cracks formed while the metal was still hot. The cracks form at the solidification boundaries and are characteristically inter dendritic. There may be evidence of segregation associated with the solidification boundary. The main cause of solidification cracking is that the weld bead in the final stage of solidification has insufficient strength to withstand the contraction stresses generated as the weld pool solidifies. Factors which increase the risk include:

- insufficient weld bead size or inappropriate shape
- welding under excessive restraint
- material properties - such as a high impurity content or a relatively large shrinkage on solidification

Joint design can have an influence on the level of residual stresses. Large gaps between components will increase the strain on the solidifying weld metal, especially if the depth of penetration is small. Hence weld beads with a small depth to width ratio, such as is formed when bridging a large wide gap with a thin bead, will be more susceptible to solidification cracking.

In steels, cracking is associated with impurities, particularly sulphur and phosphorus and is promoted by carbon, whereas manganese and sulphur can help to reduce the risk. To minimize the risk of cracking, fillers with low carbon and impurity levels and a relatively high manganese content are preferred. As a general rule, for carbon manganese steels, the total sulphur and phosphorus content should be no greater than 0.06%. However when welding a highly restrained joint using high strength steels, a combined level below 0.03% might be needed.

Hydrogen induced cracking (HIC)

HIC also referred to as hydrogen cracking or hydrogen assisted cracking, can occur in steels during manufacture, during fabrication or during service. When HIC occurs as a result of welding, the cracks are in the heat affected zone (HAZ) or in the weld metal itself.

Four requirements for HIC to occur are:

- a) Hydrogen be present, this may come from moisture in any flux or from other sources. It is absorbed by the weld pool and diffuses into the HAZ.
- b) A HAZ microstructure susceptible to hydrogen cracking.
- c) Tensile stresses act on the weld
- d) The assembly has cooled to close to ambient - less than 150^{o}C

HIC in the HAZ is often at the weld toe, but can be under the weld bead or at the weld root. In fillet welds cracks are normally parallel to the weld run but in butt welds cracks can be transverse to the welding direction.

vi Undercutting - In this case the thickness of one (or both) of the sheets is reduced at the toe of the weld. This is due to incorrect settings or procedure. There is already a stress concentration at the toe of the weld and any undercut will reduce the strength of the join.

vii Lamellar tearing - This is mainly a problem with low quality steels. It occurs in plate that has a low ductility in the through thickness direction, which is caused by non metallic inclusions, such as suphides and oxides that have been elongated during the rolling process. These inclusions mean that the plate can not tolerate the contraction stresses in the short transverse direction.
Lamellar tearing can occur in both fillet and butt welds, but the most vulnerable joints are 'T' and corner joints, where the fusion boundary is parallel to the rolling plane. These problems can be overcome by using better quality steel, 'buttering' the weld area with a ductile material and possibly by redesigning the joint.

2.2 Literature Review

2.2.1 Failure analysis of weld joints

The failure analysis of weld joints between carbon steel pipe and 304 stainless steel elbows has been carried out by Anwar Ul-Hamid, Hani M. Tawancy and Nureddin M. Abbas is reviewed. The objective is to investigate the failure of dissimilar weld metal joints in a piping system of a petrochemical plant. The process involved a reformed gas that passed through a water cooler followed by compression in a three stage centrifugal synthesis gas compressor.

Based on their research, the weld joint sample was sectioned and mounted in cross-section using standard metallographic techniques. The sample was ground with 600 grit size SiC paper and polished using 1 μm diamond paste. It was then coated with a thin layer of carbon using a carbon evaporator.

Both light microscopy and SEM were used to conduct a microstructural study of the fracture surface, base metal, weld metal and the heat affected zone. SEM/EDS analysis was used to determine the elemental constitution of microstructural features. Bulk composition of CS pipe and weld metal was verified using ICP-AES. Vickers microhardness testing was performed at the weld region and the base metal.

The light optical microscopy was used at low magnification to revealed primary circumferential crack in the CS pipe close to the weld region. Separation between the weld and the CS pipe can be seen in the low magnification macrograph.In the optical macrograph, the fracture appeared flat and brittle and had its origin at the weld region. These pinholes are material defects and were detected in significant proportions within the pipe.

The fracture at the inner surface of the pipe was continuous through the pipe circumference. On the other hand, the outer surface of the pipe exhibited localized areas that were still intact after failure. This observation indicates that the cracking originated at the inner surface of the pipe near the root weld. It also follows that the primary crack was circumferential while the leakage occurred when this crack branched and traversed through the wall thickness of the pipe.

SEM is used to examined a small portion of the weld metal taken from the sample. The morphology exhibited by the weld at different regions. The weld fracture shows intergranular separation and coarse dimples within the grains. The SEM or EDS analysis of the weld regions showed lower concentrations of Cr (14.9 wt% max) and Ni (5.9 wt% max). This indicates that the weld was diluted during welding. However, proper welding rod was selected for the process since E309 type rods are used to join dissimilar metals such as SSs and CSs. Type E309 filler metal contains 5–10% ferrite.

Microstructural examination of the damaged cross-section was conducted through the weld region in order to determine the nature of cracking. The crack, shown by the low magnification light optical macrograph, originated from the inner surface and extended towards the outer surface of the pipe. The crack did not exhibit branching and mainly traversed along the weld line. The same region at a slightly higher magnification is shown in an SEM micrograph.

Small cracks parallel to the rolling direction were also observed. These cracks were rolling defects and were not produced during service. An example of these cracks, obtained from regions away from the weld zone, is shown in the SEM micrograph. The primary crack propagated in a transgranular manner.

They also carried out the microhardness testing. The results of Vickers microhardness tests carried out at different regions of the weld cross-section sample. The hardness measured at the interface of the CS and the weld was very high and corresponds to Rockwell C 60. Other microhardness values correlate with the microstructure observed in the weld cross-section. The lowest hardness was exhibited by the pearlite-denuded zone due to a lack of carbon in the region.

2.2.2 Analysis of bagasse boiler tube failure.

The second literature review is referred to A.M. Heyes's failure analysis report, from Advanced Engineering and Testing Services. The objective of this investigation is to analyze the oxygen pitting failure of a baggase boiler tube.

The method used in this investigation is visual examination, stereo microscope examination, and electron microscopy. From visual inspection, the pitted areas showing red rusting is observed. Fireside deposits were minimal and little deterioration of the external tube surfaces was evident. However, there was a clear difference in the appearance if the fireside and rearside external surfaces, explained by the fact the roof tubes are recessed into the roof tiles to a depth of half their diameter. Both of the failure appeared to have occurred on the lower half (fireside) of the tubes. On close examination it could be seen that almost all of the pitting and cracking was on the lower half of the tubes.

A stereo microscope at magnifications up to 65x has been used to examine the pitted surfaces. Many small pits, with transverse cracks originating from them, were visible. The morphology if the pitting is consistent with that of oxygen pitting..

While oxygen pitting explains the presence of pits in the tube and is not an uncommon occurrence in boilers which have been off-line for some time, it cannot explain the observe cracking. Therefore, the cracks were examined with the aid of a Scanning Electron Microscope (SEM).

The examination of the pitted areas under SEM showed a majority of cracks to have started at pits, this being a result of the stress concentration formed by the pit. The fracture surface of the main crack was exposed, and an examination under the SEM clearly shows the cracking mechanism to be that of fatigue, as evidenced by the breach markings present on the fracture surface. It can be seen that the fatigue has, as expected originated from one of the many pits.

The conclusion is the pitting observed in the tube was a result of oxygen pitting and probably occurred during the wet storage period due to inadequate maintenance of the water levels, pH and the amount of oxygen scavenger. The most likely cause of the cracking observe on the tube is vibrations cause by a harmonic oscillation.

CHAPTER 3
METHODOLOGY

3.1 Methodology

In this failure investigation there are several techniques that have been applied in order to examine the samples and collect data. The methods combined both failure analysis and non destructive examination. There are some preparation steps that have to be done before the examination and analysis can be run. Below are the examination and analysis techniques that have been used:

1. Visual inspection.
2. Optical microscopic inspection.
3. Scanning electron microscope inspection.

All pertinent details and manufacturing data for the sample or material need to be known before starting the failure analysis. Service history for the equipment needs to be calculated and sequence of events leading to failure need to be known for further reference. Then, a complete photographic record of the failed component must be taken and the best thing is take the photograph for both failed component and non-failed component of the same equipment.

This examination is basely on visual inspections for the abnormalities of the failed component. Comparison between the failed and non-failed component need to be done visually.

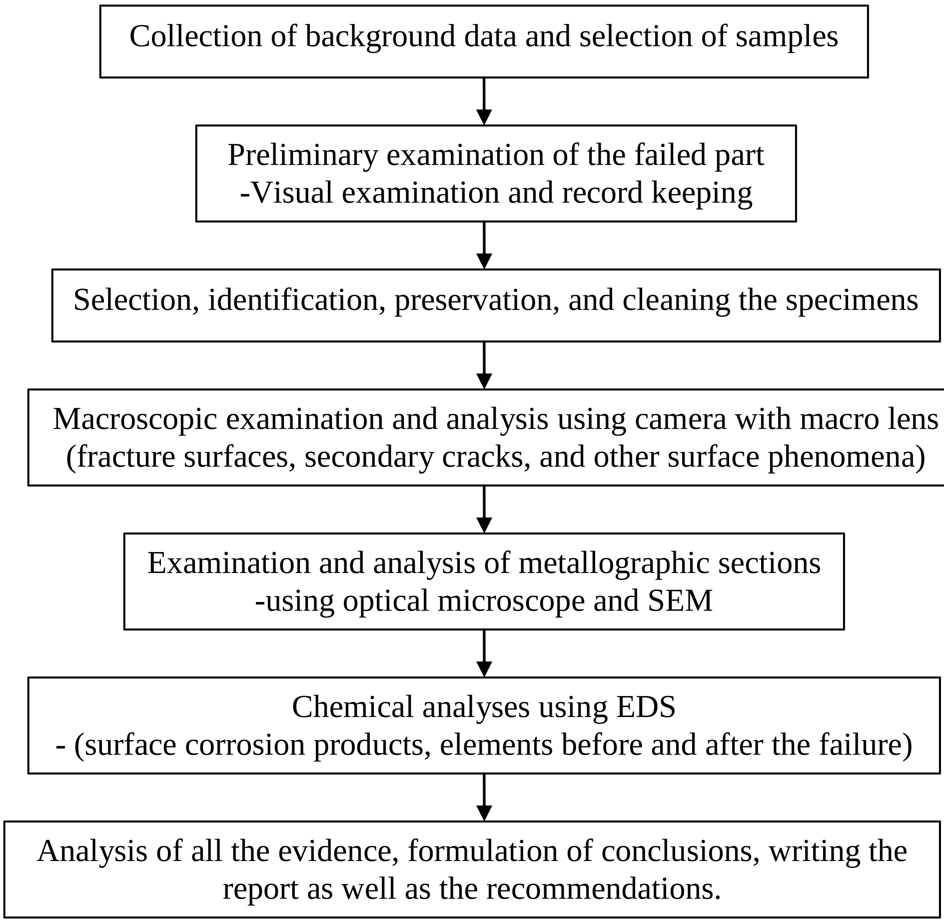

Figure 3.1. The flow of proper step to conduct failure analysis for this investigation

3.2 Background Data

The background data of the steel pipe failure was taken by interview the owner of the workshop. The data such as type of car, system that use the steel pipe and failure during operation is taken. To prove the background data, the same type of car was observe and the location of steel pipe was identified.

3.3 Sample Examination

The failure analysis of the steel pipe is focused around the area of pitting. The entire surface should be visually inspected to identify the location of the leakage-initiating site or sites and to isolate the areas in the region of crack initiation that will be most fruitful for further microanalysis. The origin often contains the clue to the cause of pitting, and both low- and high-magnification analyses are critical to accurate failure analysis.

In addition to locating the failure origin, visual analysis is necessary to reveal stress concentrations, material imperfections, the presence of surface coatings, case-hardened regions, welds and other structural details that contribute to cracking. The general level of stress, the relative ductility of the material, and the type of loading (torsion, shear, bending and so on) can often be determined from visual analysis.

3.3.1 Visual Inspection

This examination is basely on visual inspections for the abnormalities of the failed steel pipe. Comparison between the failed and non-failed of steel pipe sample need to be done visually. Visual inspection is the first step to identify the failure of the sample. The visual inspection is crucial in order to select the right part and portion of the failure tube that will be examined later on. Before the sample was cut into smaller piece, the picture of the sample is taken by using digital camera.

The macroscopic view of the failed steel pipe area is taken using digital camera with macro lens. The macroscopic examination can be used to identify the pitting surfaces and other surface phenomena.

3.3.2 Optical Microscope

The steel pipe sample was put under the optical microscope in order to examine the surface failure. Before that, the sample must be prepared as described in the sample preparation part. The surface failure pictures of the sample are taken near to the failed region of the steel pipe.

The surface topography and grain boundaries can be seen with this method under magnification of 500x, 1000x, and 5000x. The picture of surface topography was taken using AcQuis software. The pictures from surface topography can be used to interpret the type of failure mode of the steel pipe.

3.4 Sample Preparation

A common problem is that the fracture surface is dirty and contaminated. There are several methods of cleaning and prepare the sample. First, the surface of steel pipe is washed carefully, rinsed with ethanol, and then dried using dryer in order to prevent corrosion with water.

A major problem in surface preparation is the removal of rust on ferrous samples. The rust need to be removed without destroying the underlying surface which may reflect the true fracture surface topology before rusting occurred. The cleaning method involves the use of chemicals which are designed to dissolve the oxides without attacking the underlying metal. Then the steel pipe is washed with rust removal solution. The rust removal solution will remove the corrosion product from the steel pipe.

In order to examine using optical microscope and scanning electron microscope, the sample need to be prepared first. The grain boundaries can not be seen without proper surface preparation. The sample preparations are as the following:

1. The steel pipe was cut properly into a small portion using abrasive cutter.
2. Then the selected steel pipe was mounted using hot mounting technique. The sample was pressed using automatic mold press machine. Bakelite was used to form the mounted part.
3. Next, the grinding process of the sample using abrasive paper or SiC papers. The grinding process started from paper number 120, 320, 400, 600, 800, and 1200. The highest is the finest grade.
4. Polishing process using diamond water paste starting from 6μ, and 1μ. Final polishing using 1μ and 0.25μ diamond extender blue. The sample is considered completely polished when the surface is shining like mirror produced.
5. The etching process was conducted after the polishing is finished. The etchant used is 3% natal (25ml ethanol with 0.75ml acid nitric). The purpose of etching process is to reveal the grain boundaries of the steel pipe.

6. Finally, the etched sample of steel pipe was examined using the optical microscope to observe the grain boundaries of the sample. If the grain boundaries still can not be seen under optical microscope, the polishing and etching procedures need to be repeated.

For direct observation of metallic samples no preparation is required other than cleaning. However, the steel pipe samples must be electrically conducting for SEM examination, so if there is excessive rust or debris, and the surface must be observed with this on it, then it may be necessary to coat the surface with a thin layer (200 Å) of metal (such as gold or carbon).

3.4.1 Scanning Electron Microscope (SEM)

Scanning electron microscope (SEM) is a technique to investigate the failure mode with more detail. The steel pipe sample need to be prepared as discussed in the sample preparation. SEM has higher magnification level than optical microscope. The surface fracture of the pipe failure can be examined up to 5000x. The micro crack of the steel pipe can be observed with SEM machine.

SEM also can be used to compare the chemical composition at the failed region and normal region of the steel pipe. The chemical analysis of the sample can be done by Energy Dispersive X-Ray Spectrometer (EDS). From this EDS, the loss element can be determined. This technique required a vacuum space in order to prevent the electron emission from disturbed.

CHAPTER 4
RESULT AND DISCUSSION

4.1 Data Gathering, Result and Analysis

4.1.1 Visual Inspection

Before any failure analysis and nondestructive examination were preceded, the condition of the sample must be recorded and the pictures of the failure sample are taken as a record. The picture of the external part and internal part were taken. The condition of the steel pipe was capture as shown in Figure 4.1 and 4.2. The location of the leaking area is marked with red circle.

Figure 4.1: The size of the steel pipe

Figure 4.2: The picture showing the closed up view of leakage area of the pipe

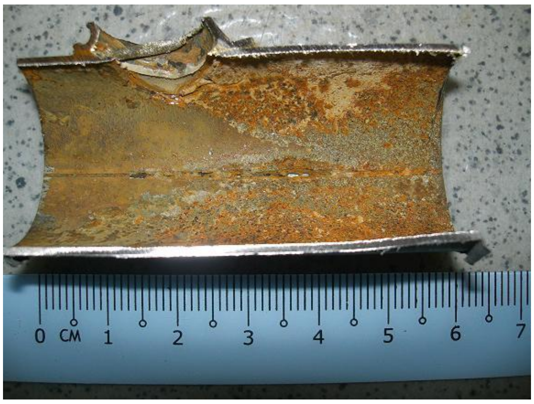

Figure 4.3: The internal view of the leakage pipe

Figure 4.4: The internal view of the pipe after cleaned with rust removal solution

After the preliminary examination, the steel pipe was cut into smaller pieces. The focused area is around the leakage. The internal wall of the pipe is show in Figure 4.3. It shows that the internal pipe experience corrosion and the most critical part that experience corrosion is on the welding line.

Then the steel pipe sample was cleaned with rust removal solution in order to remove the rust. The rust removal solution will only attack the corrosion element and not react with normal pipe material. Figure 4.4 shows the steel pipe after washed with rust removal solution.

All the pictures above will be kept as evidences before continuing to the next step of failure analysis. These pictures might be useful for the future as a reference to other data.

4.1.2 Optical Microscope Inspection

After that the investigation proceeded with optical microscopy view. A small portion of the pipe was taken near the failure area and mounted. The sample was observed with 50x, 100x, 200x and 500x magnification in order to study the surface fractography.

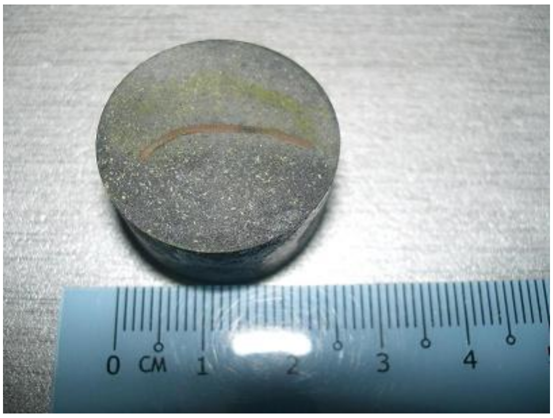

Figure 4.5: The mounted sample

The steel pipe must be mounted in order to be examined under optical microscope. Several pieces of the steel pipe have been mounted and etching with 3% natal. Figure 4.5 shows the sample of mounted steel pipe using bakelite. The use of mounted sample is very important in order to get the flat surface for examine with optical microscope. Any surface with improper flatness will cause the blur picture and will give the inaccurate result.

Figure 4.6: The grain boundary of the sample.

The grain boundaries of the steel pipe were observed using optical microscope as shown in Figure 4.6. The figure was captured along the internal wall of the steel pipe. It shows that the corrosion attack along the grain boundary. The jagged surface indicated the lost of grain boundaries.

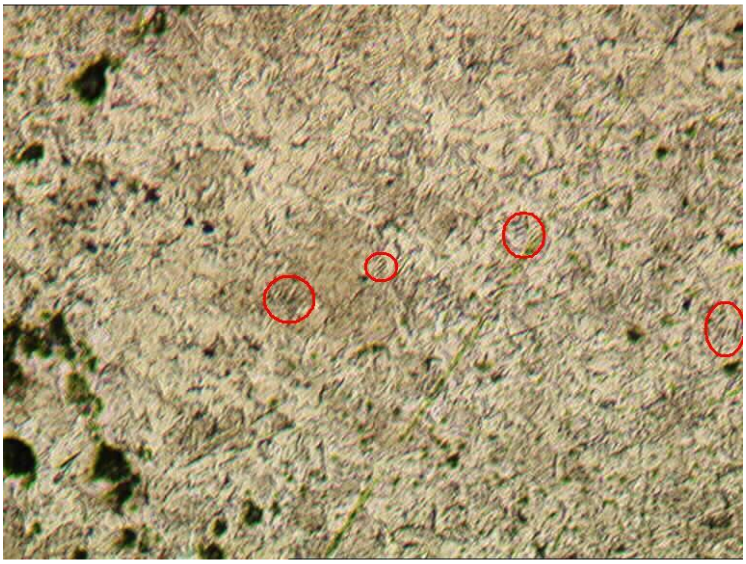

Figure 4.7: The location of slip plane in the red circles.

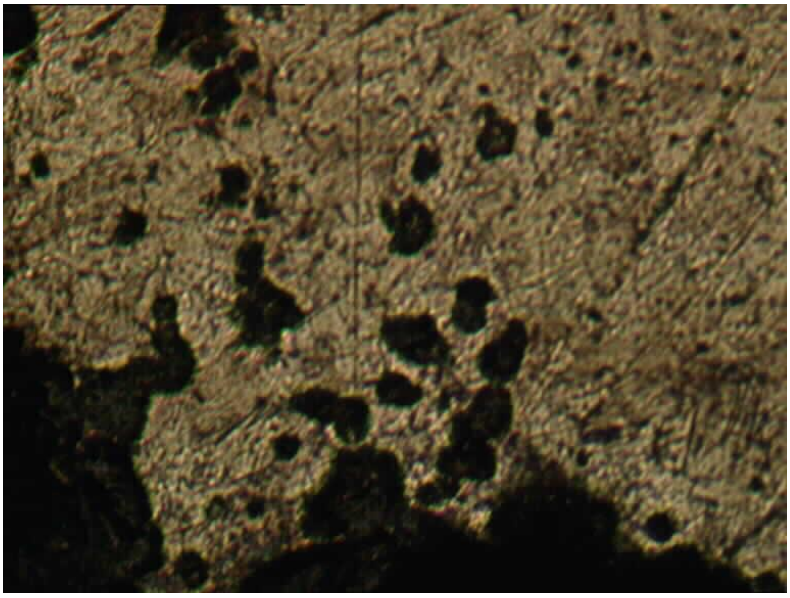

Figure 4.8: The corrosion along the grain boundaries.

The pipe experienced residue stresses, can be observed by formation of slip planes as shown in Figure 4.7 (marked with red circle). The slip plane occurred during manufacturing process, pressing of metal sheet and rolling process to form pipe. In order to form stress corrosion cracking (SCC), the metal should be under corrosion.

Mars G. Fontana has discussed about the intergranular corrosion in his Corrosion Engineering handbook, “grain boundary effects are of little or no consequence in most applications or uses of metals. If a metal corrodes, uniform attack results since grain boundaries are usually only slightly more reactive than the matrix. However, under certain conditions, grain interfaces are very reactive and intergranular corrosion results. Localized attack at and adjacent to grain boundaries, with relatively little corrosion of the grains, is *intergranular corrosion*. The alloy or metal disintegrates (grains fall out) and or loses its strength." This type of corrosion attack can be seen in Figure 4.8 and 4.9.

From ASM Metal Handbook, "intergranular corrosion takes place when the corrosion rate of the grain-boundary areas of an alloy or metal exceeds that of the grain interiors. This differences in composition between the grain boundary and the interior."

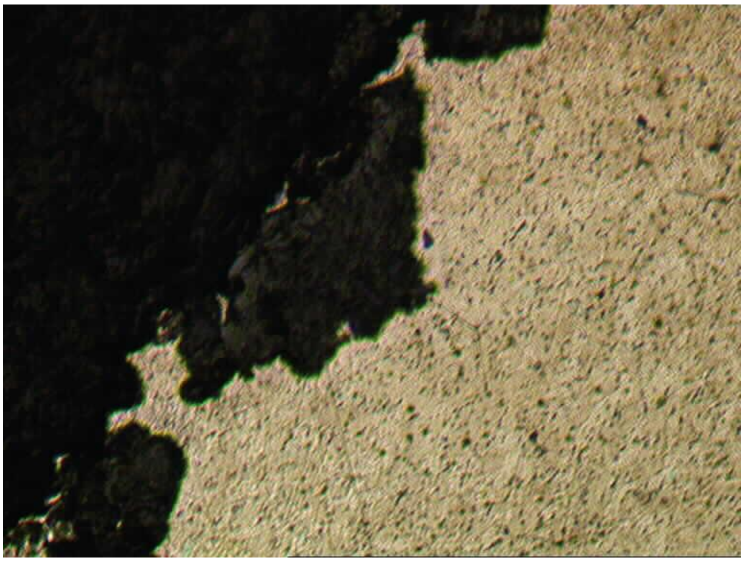

Figure 4.9: The intergranular corrosion will produce the jagged surfaces.

By looking at the microstructure surfaces in Figure 4.9, it was observed that the surfaces are rugged due to corrosion attack. The typical corrosion is intergranular corrosion as can be observed where the attack along grain boundaries. Similar work has been carried out by Stephen C. Dexter in ASM Metal handbook, page 114 [5]. Intergranular corrosion is the form of metallurgically influenced corrosion.

4.1.3 Scanning Electron Microscope Inspection

The inspection using SEM was carried out to examine the fractography of the failure tube with higher magnification. The figures below have shown the failure along the leakage pipe sample as well as the normal pipe sample.

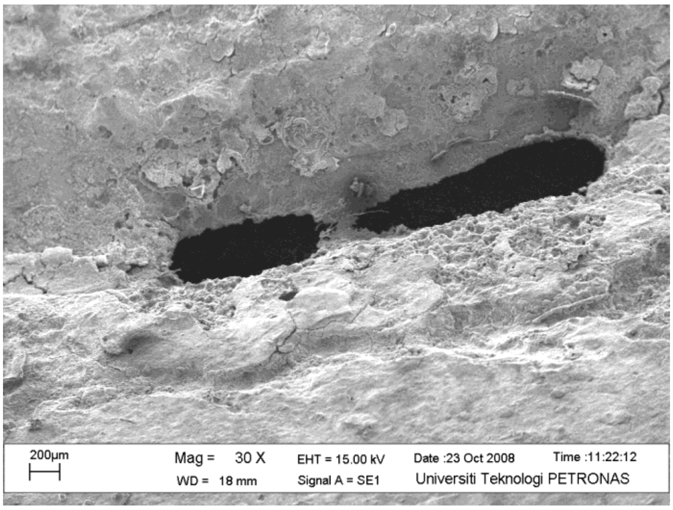

Figure 4.10: SEM fractograph shows the location of major leaking at the welding line.

The SEM examination was conducted on the welding line and internal wall of the steel pipe. From the SEM result, it shows that the welding line and internal wall were experienced corrosion. With magnification of 30x, the grain boundary is almost visible as shown in Figure 4.10. This image is taken at the major leakage area. It shows that the steel pipe has experienced corrosion attack. In Figure 4.11, the image is taken at the second leakage area on the welding line. It also indicate the corrosion attack is the cause leakage.

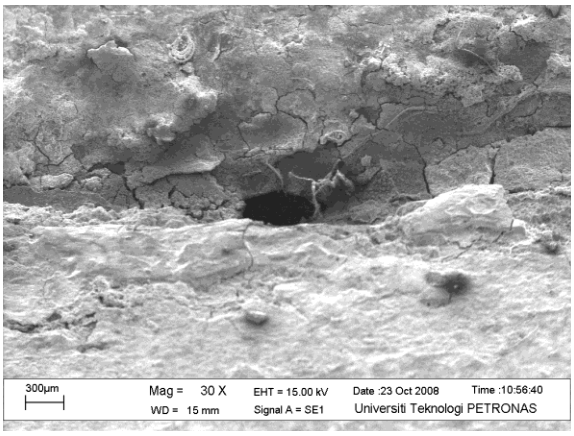

Figure 4.11: SEM fractograph shows the pin hole on welding line.

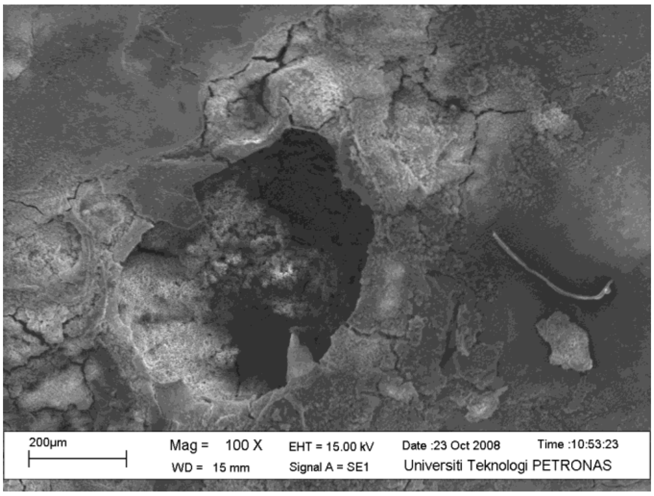

Figure 4.12: This fractography shows the micro cracks around the pin holes.

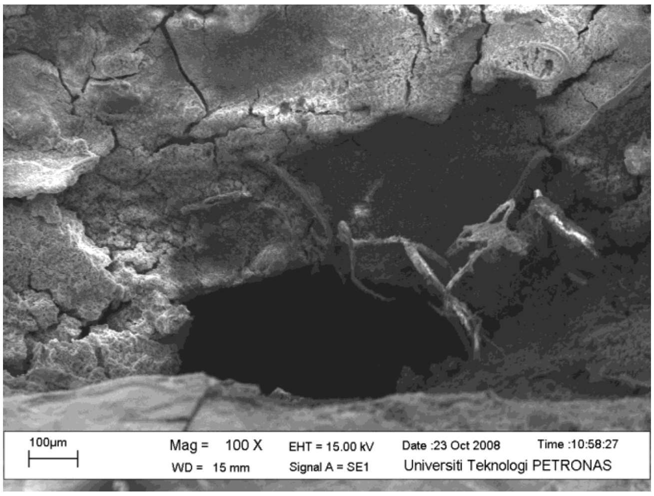

Figure 4.13: Closed up view of fractography of the pin hole area.

Then the SEM is focus on pin holes on the internal wall of steel pipe with 100x magnification. By referring to Figure 4.12, it shows that there are micro cracks around the pin hole area. The micro cracks indicated the steel pipe is experienced intergranular corrosion.

The image of different pin hole is taken using SEM with 100x magnification as shown in Figure 4.13. It also indicate the micro cracks and intergranular corrosion. The continuous lost of grain boundaries will produce the pin holes.

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4.1.4 EDS Result

Energy Dispersive Spectrometry (EDS) analyses were carried out in the leakage region and the normal region of the sample in order to know the composition of the deposits existing inside them. This provided a qualitative analysis of the relative amounts of elements present in the material.

The results are provided in Tables 4.1 and 4.2 together with the Figure 4.14 and 4.15. The results show the loss of Fe element in leakage pipe area is very critical. The Fe has been replaced by other element so the corrosion occurred.

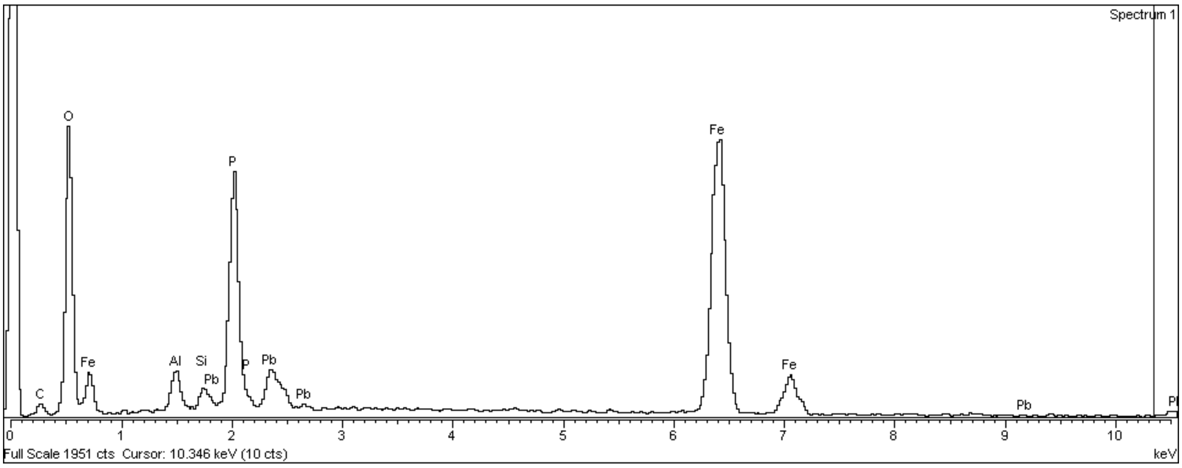

Figure 4.14: The element distribution along the failed pipe sample.

Table 4.1: The percentage of element in the failed sample.

Element	Weight%	Atomic%	
C K	6.51	12.45	
O K	44.67	64.14	
Al K	2.08	1.77	
Si K	0.93	0.76	
P K	10.98	8.14	
Fe K	29.57	12.16	
Pb M	5.26	0.58	
Totals	100.00		

Standard :
C   CaCO3
O   SiO2
Al   Al2O3
Si   SiO2
P   GaP
Fe   Fe
Pb   PbF2

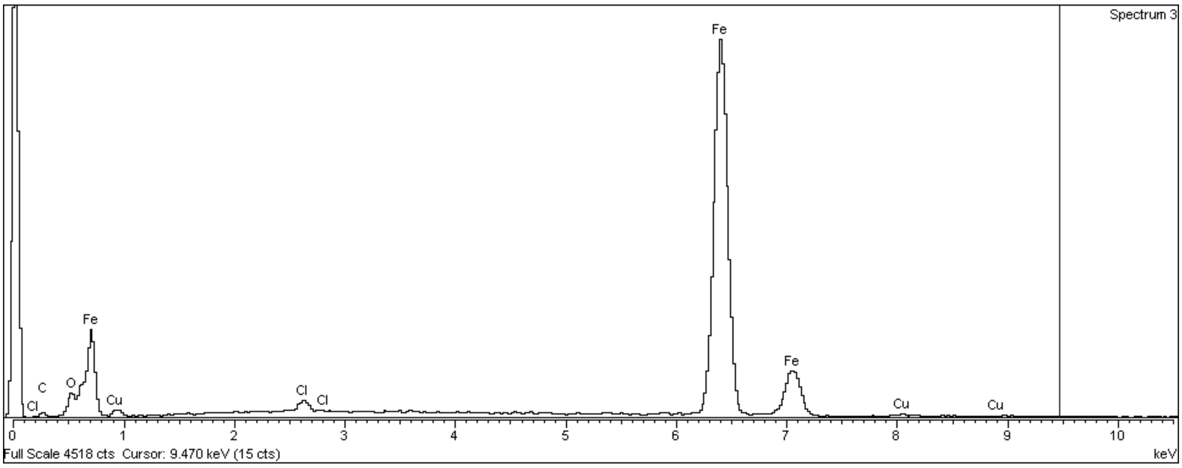

Figure 4.15: The element distribution along the normal pipe sample.

Table 4.2: The chemical composition of normal region.

Element	Weight%	Atomic%	
C K	6.36	20.98	
O K	6.89	17.06	
Cl K	1.20	1.34	
Fe K	84.75	60.12	
Cu K	0.81	0.50	
Totals	100.00		

Standard :
C   CaCO3
O   SiO2
Cl   KCl
Fe   Fe
Cu   Cu

The Figure 4.14 and Table 4.1 show the pipe experienced corrosion attack. The percentage of oxygen element in the pipe indicates that the oxidation occurred. The percentage of Fe element is small because it has been replaced by oxygen element.

Different EDS examination is taken from pipe sample that far away from failure location and the result is as in Figure 4.15 and Table 4.2. The graph and table show that the percentage of Fe element is high compare to previous data. The oxygen element percentage is very low. These qualitative results indicate that the sample is still in good condition.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The pin holes observed in the pipe was a result of internal corrosion. The type of corrosion is intergranular corrosion. The continuous of intergranular attack on the pipe wall will produce pin holes and pitting.

Intergranular corrosion can be caused by impurities at the grain boundaries, enrichment of one of the alloying elements, or depletion of one of these elements in the grain-boundary areas. For example, small amounts of iron in aluminium, wherein the solubility of iron is low, resulted to segregate in the grain boundaries and cause intergranular corrosion.[6]

The slip plane detected in microscopic inspection is produced during manufacturing process. The stress induced during formation of metal sheet and rolling processes are the result of slip plane.

As a conclusion, the pipe material experienced slip plane during manufacturing process and intergranular corrosion during its operation. The material used to produce this pipe is not good enough to operate in high pressure and high temperature as it reacts faster with acid etching.

5.2 Recommendations

The recommendation from this failure investigation of steel pipe are:

1. To use seamless type of pipe for radiator system. Seamless pipe is manufactured using extrusion technique and no welding required to form the pipe shape unlike the rolling type of pipe. The welding joint in rolling type of pipe will increase the possibility and chance for failure to occur such as stress cracking welding and heat affected zone (HAZ) along the welding line.

2. Use high quality of material that can withstand the corrosion attack such as stainless steel and carbon steel in radiator system. These type of materials have high corrosion resistance and suitable to operate at high temperature and high pressure.

3. Apply treatment process to pipe material during manufacturing process such as reheating and normalize after producing the metal sheet and extrusion process. These processes are important in order to prevent any failure during service such as plastic deformation and intergranular corrosion.

4. The ratio of addictive used in the liquid coolant must also be taken into account. The wrong mixing ratio of addictive into liquid coolant will cause the internal corrosion of the radiator pipe. The best solution is to replace all the liquid coolant with a new liquid coolant after a period of time rather than put additive. All the used liquid coolant should be flush away. Sometimes the additives will produce small particles inside the coolant after an extended service. The liquid flow with foreign particles will slowly erode the internal wall of pipe as well as the inside coating, and form the corrosion.

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APPENDICES

APPENDICES

Gantt Chart

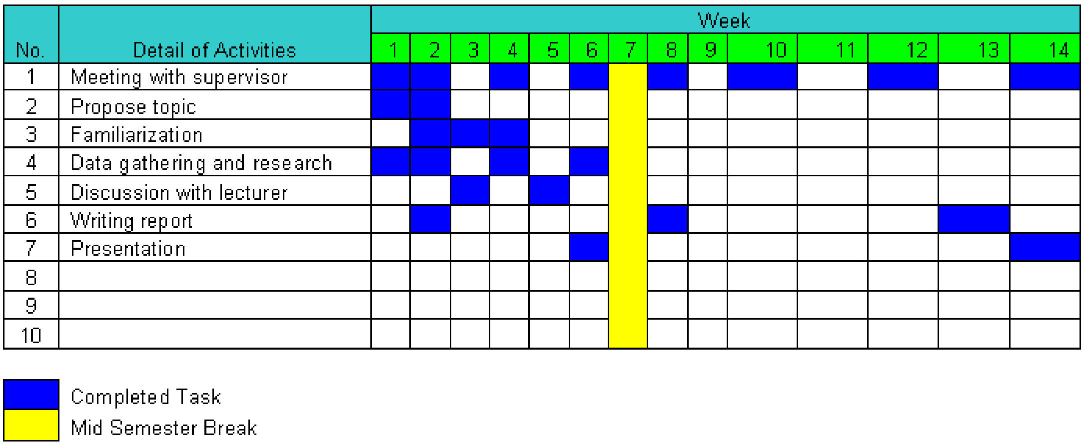

Figure 1: Gantt chart for the activities during FYP I

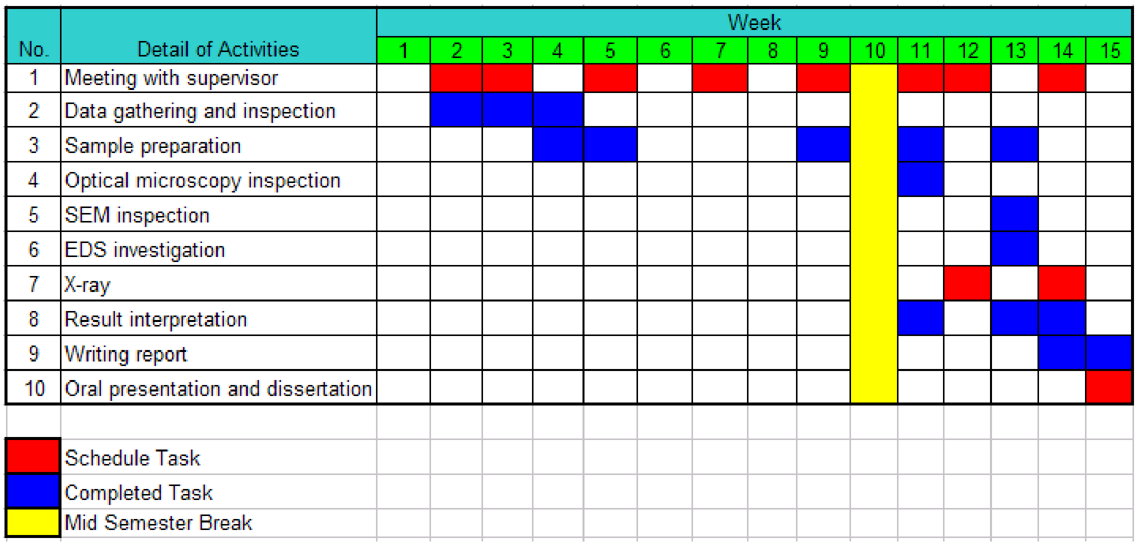

Figure 2: Gantt chart for the activities during FYP II