

FUNDAMENTAL BASIC S-N CURVE TO STUDY FATIGUE LIFE OF R260 RAIL UNDER UNIAXIAL FATIGUE TESTING

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Abstract

The main objective of this research paper is to examine the fatigue life of the R260 material specimen under uniaxial fatigue testing. Three specimens were selected to evaluate the value of ultimate tensile strength (UTS), ensuring a similar number using UTM, specifically below 250 kN. The specimens shape designed in requirement standard ASTM E8 for metal material. An experiment was conducted to determine fatigue life using eighteen bulk specimens in accordance with the standard ASTM E466-15 at seven different loading levels under uniaxial fatigue test. A Servo-Pulser fatigue machine was used with a performance of less than 100 kN, a sinusoidal signal frequency of 10Hz, and based on 20%, 30%, 35%, 40%, 45%, 55%, and 65% below the value of the ultimate tensile strength (UTS) of 1145 MPa. The value of stress ratio $R = -1$ was set up in the experiment as a principal to establish the S-N curve. The findings shows that the boundaries of low cycle fatigue regime occur at 65%, and high cycle fatigue regime occur at 35%, 40%, 45%, 55% and endurance limit occur at 20% & 30% for the total fatigue life cycles of R260. The study concludes that specific loading values significantly impact the fatigue life of the specimens, as observed from the trend in loading values. This approach is highly valuable and contributes to the known natural material behaviour related to fatigue life. This is not yet reported and it have not published yet in Malaysia light rail transit scenario.

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1.0 INTRODUCTION

Light rail transit is one of the crucial methods of transportation used to support mobility for various purposes. It plays a pivotal role in assisting the domestic demand and accelerating the growth of the economy. In order to support daily railway operations, the problem of rolling contact fatigue has been identified and has appeared over many decades due to the different rail scenarios (Tawfik *et al.*, 2022; Kim *et al.*, 2014). The modern engineering community of railway infrastructure introduced the meaning of fatigue as the formation of a crack on two metal surfaces due to cyclic loading with various stresses, respectively (Tawfik *et al.*, 2022; Rui & Kaewunruen, 2022). The stress concentration and structural discontinuities are the main critical points on the surface linked to fatigue (Azmalea, 2024; Rui & Kaewunruen, 2022). It has the potential to propagate the crack becoming failure and damage (Pereira *et al.*, 2019; Dowling *et al.*, 2020). Gren *et al.* (2024) and Cini (2012) concur that a mechanical component forced under continuous loading either hundreds, thousands or millions of times can develop defects and cracks with an increasing likelihood of the failure of the component. The failure always appears gradually, locally, and permanently by relying on the repeated stress coming out of the dynamic stress in the critical area where the number of stresses it is subjected to are less than the ultimate tensile strength (Tawfik *et al.*, 2022; Shen; 2017).

In railway track systems, the R260 rail profile is one of the leading types of material used worldwide, including in the United Kingdom, Thailand and Malaysia (Padzi *et al.*, 2023; Tawfik *et al.*, 2023). It is original from steel and typically involves hot rolled steel, specifically in the manufacturing process (Azmalea, 2024). The main advantages of this material are good high strength, good elastic modulus, and good thermal resistance (Azmalea, 2024). It plays a crucial role in the budgeting of maintenance programs for return of investment and it is recognized through regulations by the government and performs well (Azmalea, 2024; Tawfik *et al.*, 2023). A research group from ASEAN countries found that mechanical parts require an examination for fatigue because they can experience catastrophic failure constraints over time and in loading service conditions (Mazlan *et al.*, 2020).

Rails are critical for assisting train movements and the direction of the route, as well as being involved in safety and reliability as part of rail transportation. Rails are mainly subjected to cycling loading which can generate the phenomena of fatigue in most stress areas under rail-wheel contact. Tawfik *et al.* (2022) defined rolling contact fatigue (RCF) as a term used to refer to rail track systems. The appearance of major failures due to the repeated stresses of rail-wheel contact happen when in dynamic mode. Numerous defects come from RCF

including squand, shelling/spalling and head checking, which might be categorized as dangerous and are potential threat to the train due to the risk of derailment (Teng *et al.*, 2022). RCF happens in urban railways as shown in Figure 1.

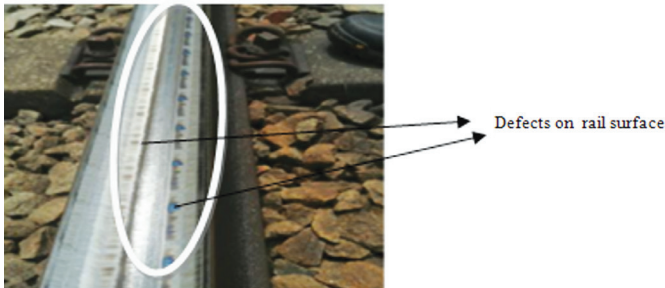


Figure 1: RCF defect of R260 at LRT

Solazzi & Mazzoni *et al.* (2023) reports that this hotspot is where the most stress happens on the component, enabling the formation of defects, cracks and the subsequent development to failure if the component is not well-designed and has not undergone the right durability assessment. For that reason, plenty of studies usually completes laboratory experiments by the manufacturer as to provide assessment reports in accordance with the standard ASTM to increase confidence when using its parts and it is making sure safe in the environment. Teng *et al.* (2022) conducts a laboratory experiment using the S-N curve to determine the characteristics of material either in terms of its vibration fatigue to verification.

Nowadays, it has lacking data on fatigue strength of R260 material. Nevertheless, a recent study of experimental fatigue life report of Gurubaran *et al.* (2017) that on the results of fatigue life for rail steel which is presented insufficient to consider their findings as used the stress ratio $R= 0.1$ to plot out the S-N curve, however instead to use $R=-1$ as principal in fatigue phenomena includes they do not apply the guidelines yet to divide the ratio to loading level to claim the safety loads and does not to reveals the way to obtain the mechanical properties (Dowling *et al.*, 2020). Their findings are less accuracy and less confident to use the way to address fatigue life. To tackle this methodology gaps, it is mandatory to obey the international standard of ASTM E8 and ASTM E466-15 regulation to set the experiment of fatigue life and to follow FKM guidelines in order to identify infinite level and safe loads. The importance of this, to ensure results correctly and properly valid as common practise for determining fatigue properties on S-N curve. In addition, to obtain fatigue life under the experiment, basic uni-axial fatigue testing apply the frequency of 10 with seven different loading level. As main objective of this research paper to investigate the fatigue failure of the sampled rail through an experiment using a Servo-Pulser fatigue machine to establish the S-N curve for the R260 rail profile. The particular significance of this study is to creating a fatigue strength record in the R260 steel database and it able to use for future reference in terms of material selection.

The work processes of this paper are organised as follows: In section 2, provides a way to set up the experiment and type of material adopts in railway. In section 3, it reveals the

findings regard R260 rail specimen on mechanical properties and total fatigue life. Finally, section 4 conclusion on the overall research.

2.0 SETTING OF EXPERIMENTAL

A details study to define the fatigue life of R260 material specimen correctly with following to standard of American Society for Testing and Materials as well as recognized international body that develop technical standard for a material. It need to fulfil the some series of processes to obtain the accurate result. The Figure 2 displays the flow chart of experimental to complete this research since begins until end. As to reduce and avoid the serious injuries and illness in conducting experiment, the author(s) mandatory to concur and have obey guidelines and practice of laboratory safety handbook - Kuala Lumpur University includes to wear the proper personal protective equipment (PPE) such as safety glasses, gloves, lab coat, safety boots and particular regulations in the handbook for machining process, tensile testing and uniaxial fatigue testing.

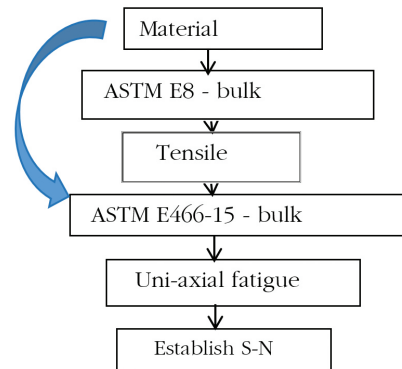


Figure 2: Flow chart of experimental

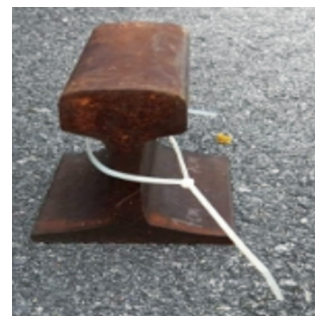


Figure 3(a): R260 material specimen

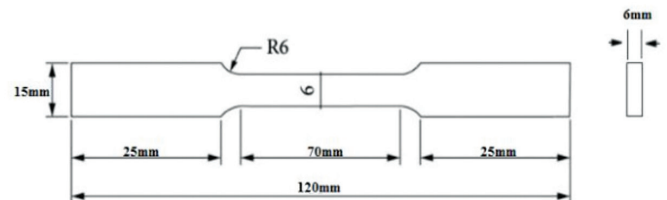


Figure 3(b): Dimension for tensile strength ASTM E8

2.1 Material Specimen

The material specimen provides through on behalf of the railway company as shown in Figure 3(a). The dimension was 7 cm x 5 cm as actual geometry. This rail profile of R260 was recognised in accordance Government of Malaysia in terms of

regulation and manufacturer. The weight designed was 60 kg/ metre (Azmalea, 2024). The material specimen can be divided into two pieces as the half piece for tensile and half piece for fatigue testing in order to saves material specimen.

2.2 ASTM E8

In order to determine the mechanical properties, the CNC machine was adopted to cut off the material specimen into some specimens as same shaped dimension of ASTM E8. The tolerance dimension to this specimens testing as in Figure 3(b).

2.3 Tensile Testing

Three specimens were used to find out the mechanical properties in tensile testing and the preparation specimens as of Figure 4(a). The Universal Tensile Machine less 100 kN have been utilized with following regulation ASTM E8 at room temperature as in Figure 4(b). The specimens subjected in axial and longitudinal forces. The forces applied on to specimen until certain deformation occur which lead to failure.

2.4 ASTM E466-15

To complete uniaxial fatigue testing, Lee *et al.* (2012) suggest to utilize the FKM guidelines that considers about some aspects such as survival rate, size correction factor and gradient factor in order to complete the uni-axial fatigue testing as Table 1 to determine the endurance limit withstand no breaking under cycling loading and to assist in dividing number of the stress ratio (R) as minimum and maximum. In this case, the R representatives as the ratio of the minimum to maximum happening in one period of a cycle as known in fully reversed in constant stress. The important to use R=-1 as set up the mean value of 0 to determine the highest loading and non-loading amplitude in form of tension-compression forces (ASTM E466-15). The advantage of R=-1 mostly adopt in myriad perspectives of the fatigue failure in S-N curve analysis

to answer the perpendicular to the loading direction either in two axis or three axis (ASTM E466-15). Some pieces of material specimen was cut off to same shape following ASTM E466-15 as can see in Figure 5(a) and (b). It requires eighteen specimens to determine the fatigue properties of R260. The dimension was 120 mm x 25 mm x 3 mm. It have polishes to all specimens to make sure no crack, no defect and no corrosion with using sand paper grid 200 in order to well perform in fatigue testing (ASTM E466-15).

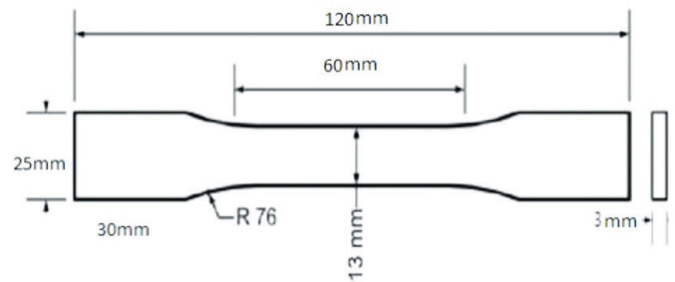


Figure 5(a): Dimension of ASTM E466-15



Figure 5(b): Real specimen

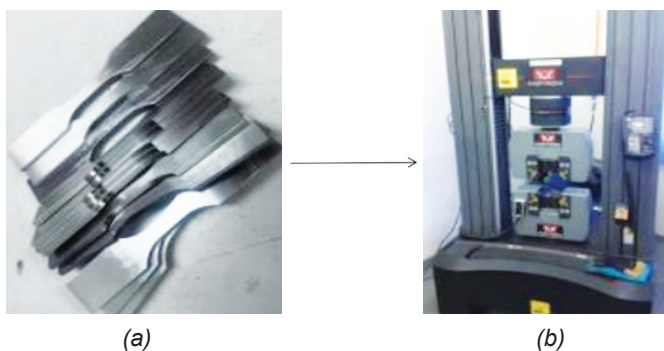


Figure 4(a): Prepares specimens
 (b): Universal Tensile Machine

Table 1: FKM guidelines parameter of uniaxial fatigue testing

No.	List of Considerations
1	$C_R=0.843(97.5\% \text{ Survival rate})$ - reliability factor
2	$C_D=1.0$ (Steel) - size correction factor
3	Gradient factor = 0.4
4	Normal temperature - 36.5°C

2.5 Uni-Axial Fatigue Testing

The Servo-Pulser less 100 kN was using to conduct the uni-axial fatigue testing. A sinusoidal waveform was applied of $f=10\text{Hz}$. A set of seven different loading used to investigate the fatigue life of 20%, 30%, 35%, 40%, 45%, 55%, 65%. Moreover, the 1.3 million cycle to failure have been setting on fatigue machine and the specimens break into two pieces surfaces considered failure. The self-adjustment of grips up and down to alignment the specimen in proper position 900. The fatigue life be gained on the experiment based ASTM E466-15. To address the categorize of fatigue life of material, three types of categorizes have been used such as low cycle fatigue (LCF) below 1000 cycle, above than 1000 until 106 as high cycle fatigue (HCF) and over than 107 fall into the endurance limit as infinite level as no break off on specimen and below the yield point.

3.0 FINDINGS

3.1 Mechanical Properties

Table 2 displays the mechanical properties obtained from the R260 rail specimens and specimens fracture as in Figure 6. The UTS and yield stress contribute highest value to compare with normal steel, cast iron and carbon steel (Dowling *et al.*, 2020). A number of UTS value for three specimens do not have significant different as in Table 3 and it is not essential to consider the effect of load correction factor caused of UTS value above than 1000 MPa (Lee *et al.*, 2012). The mean value of UTS represented to whole this experiment. However, the

values of UTS have different due of some factors includes material surface effect in machining process, unnew material and the error in experiment may possible cause the speed of machine during to capture the tension process when neglected about machine capacity as uncertain to use the standard load application velocities.

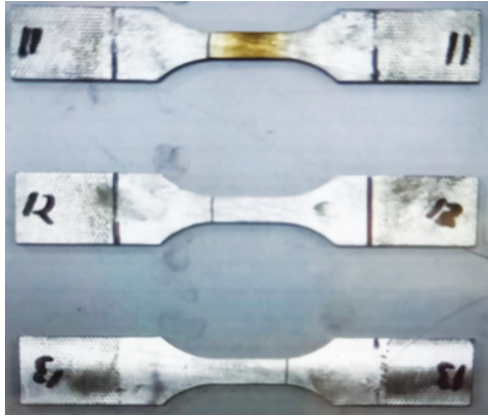


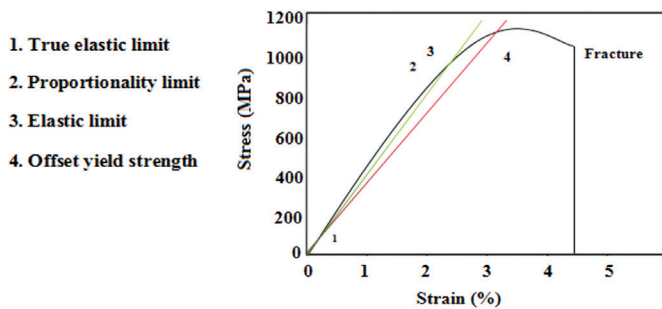
Figure 6: Specimens fracture under tensile testing

Table 2: Results of tensile strength

No. of specimen	Ultimate Tensile Strength (MPa)	Yields Stress (MPa)	Break Elongation
1	1167	1080	0.040
2	1145	1035	0.045
3	1125	1020	0.047

Table 3: Stress-strain curve of R260 for tensile strength

Area [mm ²]	UTS [MPa]	Modulus [GPa]	Yield stress [MPa]	Break elongation [mm/mm]
24.000	1145	206	1035	0.045



3.2 Fatigue Properties

Figure 7 shows that the specimens run till break off and Figure 8 demonstrates that specimens' failures of cycling loading with different stresses level. Following the Figure 9 demonstrates that stress-cycle (S-N curve) for the R260 material behaviour and key data to plot the S-N curve in Table 4. This data was falling the primary data as origin specifically in accordance standard ASTM E8 and ASTM E466-15. The trend on the stress amplitude and total number of fatigue life that 65% fall into LCF regime, 35%, 40%, 45%, 55% fall into HCF regime and 20%

and 30% fall into endurance limit. To validate this data, the trend of curves for steel with previous work were compared in the range 102 until 107 as in Figure 9. The material type of R260 is stronger than normal steel as highest trends and good ability to withstand high stress curve. Therefore, it has potential to use for long term period due of good in return of investment based on performance.

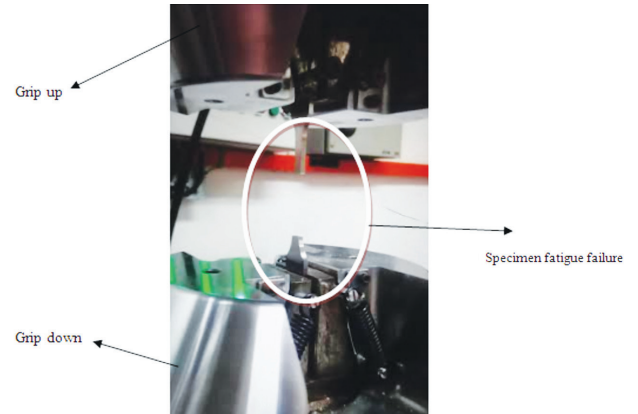


Figure 7: Specimen breaks

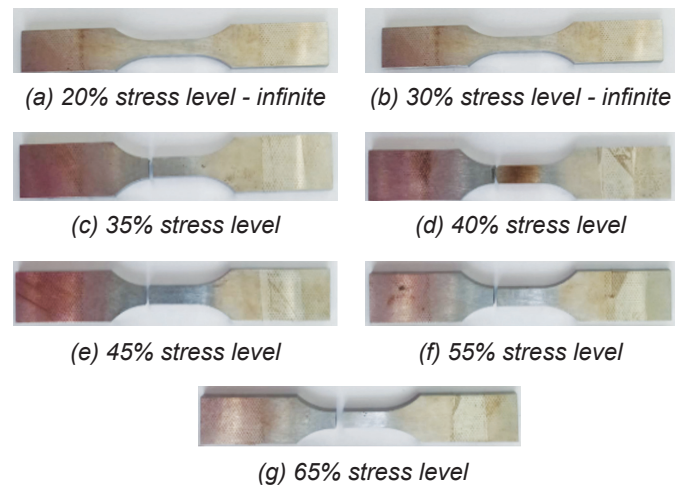


Figure 8: The specimens' failures of cycling loading with different stresses

The similar pieces of work in the context of fatigue life topic may compare to recent publication in terms of S-N curve trend is prepared of Kim *et al.* (2022). The fundamental to study the S-N curve salient to create the database for material as could help to decide in material selection through performance of any single material type in the future research. In their study, the main type material as made from aluminium alloy and it is set up of myriad different stress ratio (R) in reviewing for high cycle fatigue life. To verify the S-N curve behaviour that a number of stresses level influences the number of Nf cycle fatigue life. In Figure 9 regards the S-N curve trend as similar and it can be accepted and used for research (Kim *et al.*, 2022; Teng *et al.*, 2022).

The limitation of this research is a material specimen is unnew to obtain the real total fatigue life as given free of charge on behalf of urban railway for academic purpose.

It have diminished the ability of specimens to estimate the fatigue life. Besides, this experimental approach is focused on the uni-axial fatigue testing as suitable to find out the fatigue properties for tackling the RCF defects on rail surface nor represent to all points of defects in RCF propagation to become fatigue failure. It is pivotal to underline that the data on uni-axial fatigue is mandatory to compare with multi-axial fatigue in order to develop strong foundation as privilege to select stronger material for maintenance program. In future research, it is highly to recommend to increase a number of specimen for tensile testing and to be coating the rail specimen in order to review the longevity on fatigue life and it increase the strength of material.

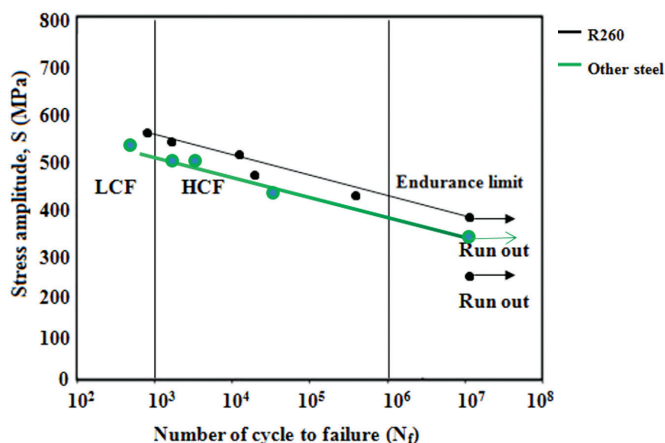


Figure 9: S-N curve of R260 versus other steel

Table 4: Data of testing for fatigue life

Pending	Pending	Pending	Pending	Pending	Pending
1	20%	5.498	-1	Passed	Infinite
2	30%	8.247	-1	Passed	Infinite
3	35%	9.6215	-1	Failure	871164
4	40%	10.996	-1	Failure	33919
5	45%	12.371	-1	Failure	33563
6	55%	15.119	-1	Failure	2923
7	65%	17.868	-1	Failure	996

4.0 CONCLUSIONS

This research is presented regard the total fatigue life for R260 rail specimen. The requirement and protocol of American Society for Testing and Materials-E8 have been fulfilled to determination the mechanical properties as of ultimate tensile strength, elongation and yield stress using tension-tension force in condition of room temperature 36.5°C through three specimens evaluation separation in tensile testing. To address the S-N curve, the uniaxial fatigue testing was successfully applied to the specimens with seven different loading below UTS for examining the variation of stress level and important to observe fatigue strength characteristics, respectively. The findings shown that the 20% and 30% loading level fall into endurance limit as above than 10⁷ withstand never break to fatigue failure, and 35%, 40%, 45% fall into high cycles fatigue (HCF) regime as above 10⁴ number cycle to failure and 55%

and 65% fall into low cycles fatigue (LCF) regime as below 10⁴ and it has well compared with the other steel on the S-N curves and trends. It can be mentioned that R260 is strong material and good fatigue strength as can sustain for long term period. The benefits of this implications highlights the fatigue properties on material R260 though S-N curve and it can be used for validation databases of steel material.

5.0 ACKNOWLEDGMENTS

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PROFILES



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