International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:8, No:4, 2014

Useful Lifetime Prediction of Rail Pads for High Speed Trains

Chang Su Woo, Hyun Sung Park

***Abstract*—**Useful lifetime evaluation of railpads were very important in design procedure to assure the safety and reliability. It is, therefore, necessary to establish a suitable criterion for the replacement period of rail pads. In this study, we performed properties and accelerated heat aging tests of rail pads considering degradation factors and all environmental conditions including operation, and then derived a lifetime prediction equation according to changes in hardness, thickness, and static spring constants in the Arrhenius plot to establish how to estimate the aging of rail pads. With the useful lifetime prediction equation, the lifetime of e-clip pads was 2.5 years when the change in hardness was 10% at 25°C; and that of f-clip pads was 1.7 years. When the change in thickness was 10%, the lifetime of e-clip pads and f-clip pads is 2.6 years respectively. The results obtained in this study to estimate the useful lifetime of rail pads for high speed trains can be used for determining the maintenance and replacement schedule for rail pads.

***Keywords*—**Rail pads, accelerated test, Arrhenius plot, useful lifetime prediction.

I. Introduction

TRAINS have been a typical mean of mass transportation that has an advantage in their reliability and economic efficiency. According to demands for more rapid transportation in modern times, recent trains have become faster and faster. Moreover, it requires the development need of several conveniences and rail engineering to meet the demand of passengers who want a quiet, comfortable and safe ride [1], [2].

Rail pads, that can prevent the breaking of railroad ties and roadbeds by reducing the shock of train loads transferred to railroad ties as well as securing the elasticity of all railroads, have been the center of much concern and research and have led to efforts to reduce vibration and noise generated by trains and rails due to the high speeds at which they travel [3]-[5].

Experimental and analytic research has been conducted in Europe and Japan to analyze the effects of changes in physical properties by the degradation of rail pads. Related technology developed in Korea including design, analysis, and the estimation of performance and useful lifetime is very incompetent and all related products had to be imported.

Securing domestically developed technology is a requirement to escape from dependence on foreign technology. There is no reference for the replacement period of rail pads considering passing tonnage and weather factors, and also there was little research on quantitative and qualitative analysis to investigate how the hardness of rail pads affects the behaviors of rails. In particular, there is no reliable data on rail pads, a critical factor for the reliability of the railroad industry. It is, therefore, necessary to quantify the heat aging processes through the property tests of rail pads. In this study, we performed property and accelerated heat aging tests of rail pads considering degradation factors and all environmental conditions including operation, and then derived a useful lifetime prediction equation according to changes in hardness, thickness, and static spring constants in the Arrhenius curve to establish how to estimate the aging of rail pads.

C. S. Woo is with the Korea Institute of Machinery and Materials, Daejeon, Korea (corresponding author to provide phone: 82-42-868-7882; fax: 82-42-868-7884; e-mail: cswoo@ kimm.re.kr).

H. S. Park was with the Korea Institute of Machinery and Materials, Daejeon, Korea. He is now with the Department of Nano-Mechanics, (e-mail: hspark@kimm.re.kr).

II. Property Tests of Rail Pads

A. Degradation of Rail Pads

Rail pads are one of the components that come into contact with the rail. Rail pads are used as a part of rubber composites in fastening devices connecting railroad ties as shown in Fig. 1. Rail pads reduce the amount of shock transferred from rails to protect railroad ties. These rail pads become hard and their elasticity becomes reduced as the passing tonnage and usage period increases, resulting in negative effects on the tracks. As the strength of the rail pads increases, the wheel load of vehicles increases and components of tracks such as rails, fastening devices, railroad ties, and ballast tracks are likely to suffer damage. This shortens the replacement period of track components and increases vibration, threatening the safety of vehicles and living environments around railroads. It is, therefore, necessary to establish a suitable criterion for the replacement period of rail pads. There were, however, few studies on such criterion.

In this study, we analyzed changes in hardness, thickness, and strength by the degradation of rail pads to quantify their aging. The degradation of rail pads is a problematic phenomenon due to changes in mechanical properties, appearance, and shape by internal factors, including the composition of rubber composites as well as external factors including the environment: these factors play roles as several forms while each one acts independently. For example, heat (temperature), oxygen, ozone, and light always contribute to mechanical degradation factors such as load and vibration condition. The phenomena resulting from these factors eventually leads to crosslink cutting (adhesion) and crosslink processing (hardening), and ultimately to cracking and failure.

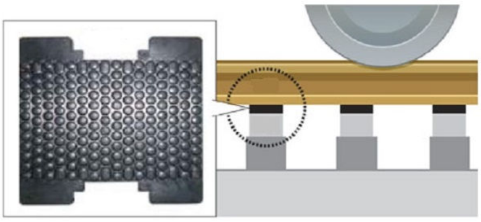


Fig. 1 Rail pad for high speed railway vehicles

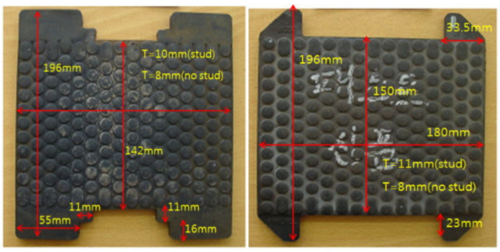
B. Property Tests of Rail Pads

Considering the load and temperature that have the most significant impact on changes in the properties of rail pads, e-clip pads and f-clip pads for high speed trains as shown in Fig. 2 were thermally aged for 55 days at 70°C, 85°C, and 100°C (higher than actual temperatures) as well as at room temperature, and then changes in physical properties such as hardness, thickness, and static spring constants of rail pads during specific periods were measured.

The hardness and thickness of e-clip pads at room temperature were 72 HD and 10.18mm; and those of f-clip pads were 66 HD and 10.86mm. Hardness and thickness under aging temperature and period were measured with compression set devices used in mechanical property tests of vulcanized rubber conforming to ISO 815. Rail pads were taken out of the aging testers and separated from compression devices. Then, the rail pads were kept for thirty minutes at room temperature and their hardness and thickness were measured.

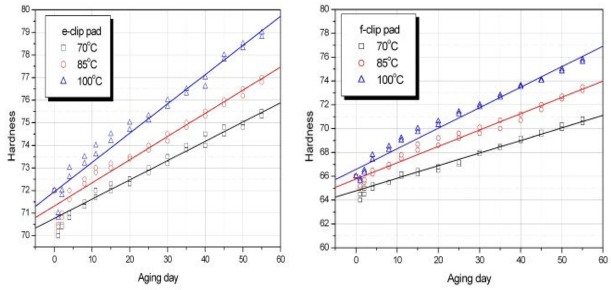
Figs. 3 and 4 show the changes in hardness and thickness depending on the aging period at room temperature: The changes are proportional to temperature and aging period. To measure changes in the load of rail pads and its relation to displacement, a load was applied to rail pads using loading plates with the same width as the nominal width of their bottom. The range of the load was 0~95kN. After 4 tests, excluding the results from the first test the remaining test results were averaged and the static spring constant was measured.

Fig. 5 shows changes in the static spring constant at the thermal aging condition: the constant drastically increases as temperature rises and the aging period is extended.



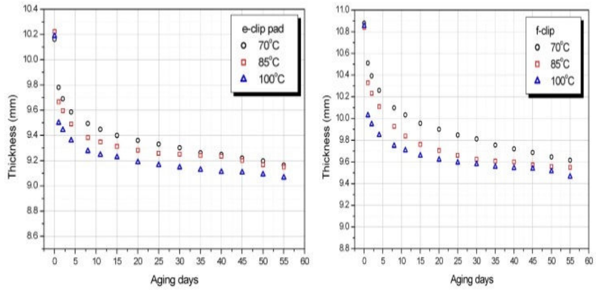
(a) e-clip pad (b) f-clip pad

Fig. 2 Configuration of rail pads



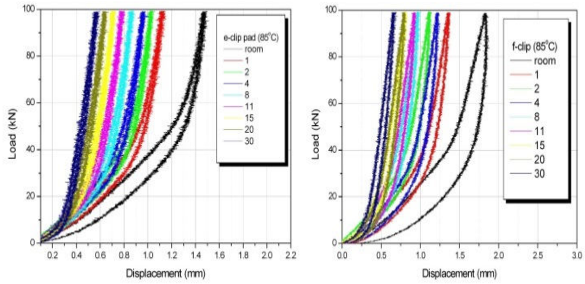
(a) e-clip pad (b) f-clip pad

Fig. 3 Hardness variation of rail pads



(a) e-clip pad (b) f-clip pad

Fig. 4 Thickness variation of rail pads



(a) e-clip pad (b) f-clip pad

Fig. 5 Spring constant variation of rail pads

III. Useful Lifetime Prediction of Rail Pad

A. Arrhenius Model

It is difficult to estimate the useful lifetime of rubber products because its processing environment and condition are complicated and there are a variety of use and combination conditions and degradation factors such as temperature, humidity, ozone, light, mechanical and electric stress. In particular, it is very difficult to design tests to estimate useful lifetime under the same conditions as in actual use [6].

In this study, the Arrhenius model was selected to estimate the useful lifetime of rubber material with data obtained by acceleration heat aging test, in which we adapted the an acceleration method where the rubber is thermally aged.

In the Arrhenius model, the useful lifetime is determined by the time when specific change from the initial state of a property occurs over temperature, and the useful lifetime is represented by the master curve and the relation of time and temperature. Through this relationship the lifetime of rubber can be estimated at a particular temperature. The lifetime by natural aging at room temperature can be estimated using data obtained in acceleration tests. Assuming that the value of a property of rubber is P in the aging reaction, the Arrhenius equation can be represented as in (1):

$$-\frac{dP}{dt} = kP,\ \ln[\frac{P}{P_0}] = -kt \tag{1}$$

where, P : the value of a property of rubber, P_0 : the value of the property before aging, t : time, and k : reaction rate.

In (1), the reaction rate k is a constant that represents the going reaction of the value of the property. In 1889, S. Arrhenius obtained the empirical equation as in (2):

$$k = A \cdot e^{-E/RT},\ \ln k(t) = -\frac{E}{RT} + C \tag{2}$$

where, A and C: constant, E : activity energy(J/mol K), R : constant of gas(8.314 J/mol K), and T : absolute temperature .

In (1), the lifetime (t) can be derived from (3). If lifetime is plugged in for time when there is the value of the aged property (P).

$$t = -\ln(P/P_0)/k \tag{3}$$

In (3), the lifetime (t) can be transformed to temperature because the lifetime can be related with temperature in the reaction rate relation (2). That is, the lifetime t_1 at temperature T_1 is equal to the lifetime t_2 at temperature T_2 for the value of the property (P). This can be represented by (4):

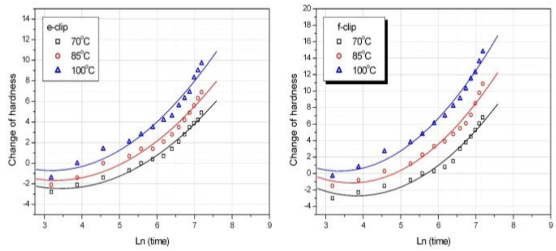
$$\ln[\frac{t_1}{t_2}] = \frac{E}{R}[\frac{1}{T_1} - \frac{1}{T_2}] \tag{4}$$

Long term changes at low temperature are the same with short term changes at high temperature. Changes at room temperature for several years, therefore, can be estimated under accelerated aging conditions at high temperature.

B. Useful Lifetime Prediction

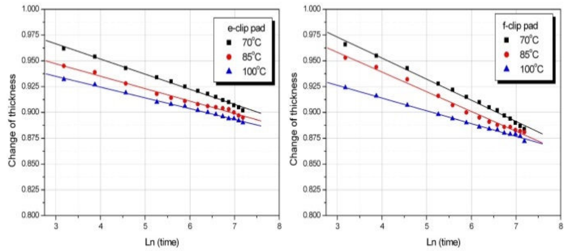
Using data obtained through accelerated heat aging tests in which useful lifetime is determined in short period with more severe conditions than actual cases, the useful lifetime of rail pads was estimated with the Arrhenius relation.

Figs. 6 and 8 show changes in hardness, thickness, and the static spring constant of rail pads depending on aging temperature and period: the changes were proportional to aging temperature and period. To represent changes in the hardness and thickness of rail pads over temperature, the time in the x-axis was linearized in the logarithmic scale and the y-axis indicates changes in physical properties with respect to the initial conditions.



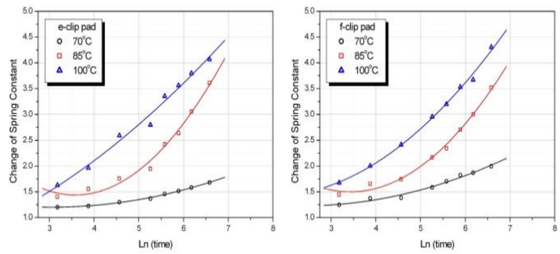
(a) e-clip pad (b) f-clip pad

Fig. 6 Change in hardness at various temperatures



(a) e-clip pad (b) f-clip pad

Fig. 7 Change in thickness at various temperatures



(a) e-clip pad (b) f-clip pad

Fig. 8 Change in spring constant at various temperatures

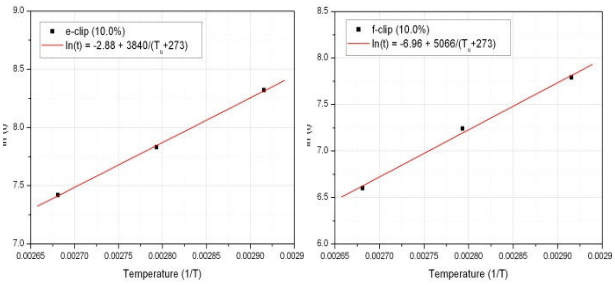
Arrhenius curves in Figs. 9 and 11 were obtained from changes in the physical properties of rail pads over time at 70°C, 85°C, and 100°C. The useful lifetime estimation equation could be derived in Table I using the least square method.

With the useful lifetime estimation equation, the lifetime of e-clip pads was 2.5 years when the change in hardness was 10% at 25°C; and that of f-clip pads was 2.6 years. When the change in thickness was 10%, the lifetime of e-clip pads was 1.7 years and that of f-clip pads was 2.6 years. When the change in the static spring constant was 50%, the useful lifetime of e-clip pads was 6.9 years and that of f-clip pads was about 1 year.

TABLE I
USEFUL LIFETIME PREDICTION EQUATION OR RAIL PADS

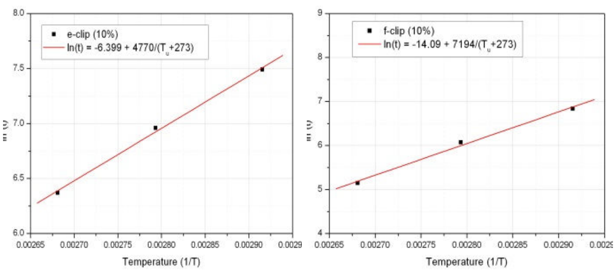
Rail Pad	Change of characteristics	Prediction equation	Lifetime (years)
e-clip	Hardness	$\ln(t)=-2.88+3840/(T_u+273)$	2.5
	Thickness	$\ln(t)=-6.40+4770/(T_u+273)$	1.7
	S/P constant	$\ln(t)=-29.7+12135/(T_u+273)$	6.9
f-clip	Hardness	$\ln(t)=-6.96+5066/(T_u+273)$	2.6
	Thickness	$\ln(t)=-14.1+7194/(T_u+273)$	2.6
	S/P constant	$\ln(t)=-22.0+9210/(T_u+273)$	0.8

Where, T: Useful lifetime, T_u: Using temperature



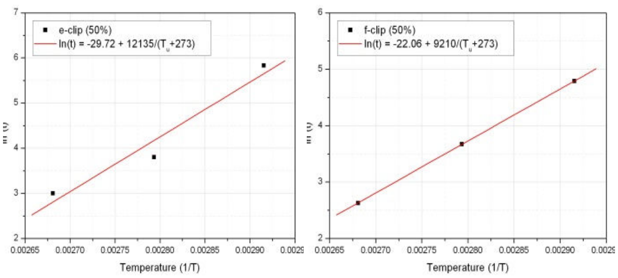
(a) e-clip pad (b) f-clip pad

Fig. 9 Arrhenius plot for hardness variation



(a) e-clip pad (b) f-clip pad

Fig. 10 Arrhenius plot for thickness variation



(a) e-clip pad (b) f-clip pad

Fig. 11 Arrhenius plot for spring constant variation

IV. CONCLUSION

In this study, the useful lifetime of rail pads for rail fastening devices of high speed trains was estimated, considering their operation and environmental conditions. We concluded as follows:

1) The changes in hardness, thickness, and static spring constant were obtained via heat aging tests at various temperatures to estimate the useful lifetime of rail pads.
2) The useful lifetime prediction equations were derived according to changes in the physical properties of rail pads, using Arrhenius curves after performing acceleration tests by heat aging.
3) With the useful lifetime prediction equation, the lifetime of e-clip pads was 2.5 years when the change in hardness was 10% at 25°C; and that of f-clip pads was 1.7 years. When the change in thickness was 10%, the lifetime of e-clip pads and f-clip pads is 2.6 years respectively. When the change in the static spring constant was 50%, the lifetime of e-clip pads was 6.8 years and that of f-clip pads was about 1 year.
4) The results obtained in this study to estimate the useful lifetime of rail pads for high speed trains can be used for determining the maintenance and replacement schedule for rail pads. This would greatly contribute to estimated reliability of rail pads owing to advances in useful lifetime estimation skills.

ACKNOWLEDGMENT

This study disclosed one part of the "estimation of the proper replacement period of fastening devices for high speed trains," a project supported by the Korea Railroad Research Institute. We are grateful to those at the Korea Railroad Research Institute and Korea Rail Network Authority.

REFERENCES

[1] A. K. Chopra, “Dynamics of structure-Theory and applications to earthquake engineering,” University of California at Berkeley Prentice Hall, 1995.
[2] S. C. Yang, H. C. Noh, Y. S. Kang, and J. D. Lee, “Development of sleeper for high speed railway,” *Korea society for railway Trans.*, pp. 311-318, 2000.
[3] Y. G. Park, K. D. Kang, and J. Y. Choi, “A behavior analysis of HSR concrete slab track under variety of rail pad static stiffness on fatigue effect,” *Korea society for railway Trans.*, vol. 10, No. 5, pp. 499-505, 2007.
[4] J. S. Koo, and Y. H. Yun, “Crashworthy design and evaluation on the front-end structure of high speed train,” *IJAT*, vol. 5, No. 3, pp.173-180, 2004.
[5] S. T. Kwon, S. H. Na, and J. N. Kim, “A comparative study on mechanical properties of rail pad material,” *Korea society for railway Trans.*, vol. 5, No. 3, pp. 62-675, 2004.
[6] R. P. Brown, T. Butler, and S. W. Hawley, Aging of rubber-accelerated heat aging test results, *RAPRA Technology,*2001.

Chang Su Woo graduated in mechanics at the Seoul National University and went on to do a PhD. He was recruited in 1989 by the Korea Institute of Machinery and Materials (KIMM) to work on fatigue analysis of mechanical component, but later turned to research on design and analysis of rubber engineering components, working with colleagues both on choice of characteristics to meet the give function and on design methodology for meeting those characteristics. Particular areas are stress-strain and failure properties, and the use of simulation software such as finite element analysis (FEA) to predict the related component characteristics such as load-deflection behavior and lifetime. He has published approximately 50 papers relating to research on rubber engineering components and their applications, such as automotive mounts and bushings, suspension of railway vehicles, shock & vibration isolators, marine fenders and structure energy dissipation systems.