Songklanakarin J. Sci. Technol.
32 (4), 387-390, Jul. - Aug. 2010

Songklanakarin Journal
of Science and Technology

http://www.sjst.psu.ac.th

Original Article

Measuring service life and evaluating the quality of solid tires

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Received 23 August 2009; Accepted 5 July 2010

Abstract

The objective of this research is to propose procedures for measuring service life and evaluating the quality of locally made and used solid tires in Thailand. The solid tires were stressed and rotated until blowout on a drum-like test apparatus which is designed, constructed by the authors and equipped with laboratory instrumentation. Solid tires from five different manufacturers were selected for testing. We measured service life, length of time to tire failure, at three different loading amplitudes and three different speeds on the testing drum. The service life of all specimens was studied and compared to determine the possibility of using service life to evaluate the quality of a solid tire.

Keywords: solid tire, quality, service life, blowout testing

1. Introduction

Solid tires made of natural rubber, manufactured and used for forklift trucks in Thailand, have quality problems involving vibration, non-uniformity and unbalanced rotation (Chetpattananondh *et al.*, 2008). Failure of solid tires may occur from excessive loads and/or heat generation inducing loss of mechanical properties. Now we consider the failure of solid tires relating to heat generation. Solid tires used under severe conditions, such as overloading, high speed, or high temperature work places often fail and blowout. When they are rolling and carrying load continuously, the rubber is stressed and deformed leading to heat generation (Gent, 1992). The hysteresis loss due to internal friction in the rubber links the strain energy density to the heat source (Lin *et al.*, 2004; Sridhar *et al.*, 1999). This causes temperature to rise to a critical level and finally destroys the solid tire. The blowout of rubber blocks is the consequence of sufficient quantities of a volatile decomposition in rubber compound at high temperature (Gent *et al.*, 1998). For a pneumatic tire, it is reported that the expansion of air with temperature, thermal weakening of tire structure and potential chemical reactions cause blowouts and explosions (Dolez *et al.*, 2008). The failure of a pneumatic tire may be investigated and observed easily from tread belt separation. The quality control of pneumatic tires may be performed in laboratory tests such as endurance, high speed performance test and peeling test to measure and evaluate the potential to fail (Ratrout *et al.*, 2006). The solid tires in Thai market have failure problems because of use under severe conditions including high humidity and high temperature environment. The solid tire manufacturers now can control the quality only in relation to dimensions and load capacity (JIS D6405, 1990). Recently in the market, solid tire brands show differences in designs, structures, rubber compositions, and reinforcements, but manufacturing defects and errors continue to appear for all manufacturers. They cannot measure or evaluate their product's qualities relating to failure from heat

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build up due to the lack of a test method, test equipment, test procedures and criterion. Consequently, the way to improve the ability of solid tires to resist heat degradation and failure is to design appropriate testing methods.

In the past, no research was conducted on the measurement and evaluation in terms of service life and quality of local market solid tires being used in Thailand. This is probably due to the unavailable of a testing machine for solid tires. Thus, this research started with the designing and constructing of the drum-like test apparatus before conducting of the study. The success of the study will be of value to the solid tire industries in Thailand.

2. The Concept of this research work

2.1 Concept of drum testing machine

There are several types of tire testing and setup depending on test characteristics (Tönük *et al.*, 2001). In this study, only the normal force acting on a solid tire was considered. Thus, the drum-like testing machine that forced a tire in the horizontal direction as presented schematically in Figure 1.was designed and constructed. The advantages of this machine are rigidity, simplicity, low cost and simultaneous testing of two tires.

The machine frame is made of steel to support the drum, loading equipment, and instrument. There is a rubber isolator between the concrete foundation and the machine to absorb vibration. An AC variable speed motor of 10 HP with the maximum speed of 1,450 rpm is coupled to the gear reducer with a ratio of 10:1. The V-belt transmits torque and rotation from a gear box to the drum with a speed ratio of 1:1. The drum has a diameter of 900 mm, surface width of 300 mm, and weight of 1,500 kg. It is manufactured by casting, surface hardening and machining. The speed of drum is adjustable from 10-20 km/hr by variable speed controller. The spindle is designed to fit with the tire rim. Each tire specimen is positioned and loaded to contact the drum by hydraulic cylinder. The deformation of solid tire during loading is measured by displacement transducer and the force acting on the drum is measured by pressure transducer. The data of force and deformation is fed to a LABVIEW data acquisition card. For safety, a thick transparent plastic sheet was be used as a cover on the machine to protect the operator from hot tire fragments after blowout.

2.2 Tires and testing

The reference group of new, industrial solid tires, size 6.00-9 as used in the local market of Thailand, was selected from five brands and coded as A, B, C, D and E in this study and is shown in Figure 2. The tires weighed 25 kg each, had a width of 139 mm, overall diameter of 525 mm, and of load capacity of 1,900 kg. The blowout test was performed to measure the service life at three different speeds: 10 km/hr, 15 km/hr and 20 km/hr. In addition, three different horizontal loads of 1,200 kg, 1,600 kg, and 2,000 kg were applied. Each solid tire was tested until blowout occurred, but not exceeding 24 hours. To test the service life, the tire was installed and fastened to the spindle with special bolts and nuts. The tire and drum were in alignment within contact plane. The testing started by moving the tire into contact with the drum and running the machine at 6 km/hr and load of 1,000 kg for about 10 minutes. After that, the drum speed was increased up to the test speed and the tire was compressed until the horizontal testing load was reached. At this point data collection was started. During the test, it was necessary to control the constant loading amplitude because the variation of tire stiffness and loss of modulus by heat build up altered the pressure in the hydraulic cylinder. When the tire reached failure, the machine and data collection stopped. If the tire did not blowout by 24 hours, the machine was stopped. The tire was removed after cooling for 30-45 minutes or upon reaching room temperature.

3. Results and Discussion

3.1 Measuring Service life

Table 1. presents service life defined as time and distance of new industrial solid tire, size 6.00-9 in local market of Thailand at speed of 10, 15 and 20 km/hr and load of 1,200

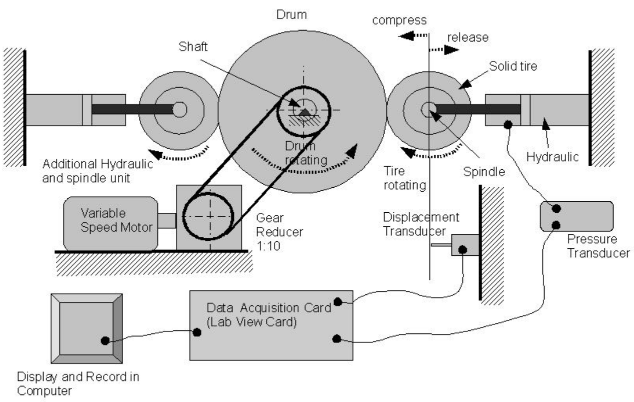

Figure 1. Drum-like testing machine.

Figure 2. Tire specimens size 6.00-9 of five different brands.

Table 1. Service life of reference group of solid tires (Brand name tires) size 6.00-9 test at speeds of 10, 15 and 20 km/hr.

Brand	Load(kg)	Service life (hr)			Distance(km)		
		10 km/hr	15 km/hr	20km/hr	10 km/hr	15 km/hr	20km/hr
A	1,200	24.00*	8.73	4.02	240.00*	131.00	80.33
	1,600	13.33	3.83	1.88	133.33	57.50	37.67
	2,000	6.68	2.83	1.20	66.83	42.50	24.00
B	1,200	24.00*	6.60	3.72	240.00*	99.00	74.33
	1,600	11.57	2.75	2.12	115.67	41.25	42.33
	2,000	7.53	2.33	1.37	75.33	35.00	27.33
C	1,200	24.00*	3.57	1.83	240.00*	53.50	36.67
	1,600	5.90	2.03	1.40	59.00	30.50	28.00
	2,000	2.65	1.47	0.90	26.50	22.00	18.00
D	1,200	24.00*	9.63	4.03	240.00*	144.50	80.67
	1,600	24.00*	3.75	2.08	240.00*	56.25	41.67
	2,000	6.22	2.28	1.42	62.17	34.25	28.33
E	1,200	6.70	3.48	2.08	67.00	52.25	41.67
	1,600	3.17	1.70	1.00	31.67	25.50	20.00
	2,000	2.35	1.32	0.78	23.50	19.75	15.67

* not blowout

1,600 and 2,000 kilograms. An increase of load and/or speed decreased the service life of tested tires. At the medium and high test speed, 15 and 20 km/hr, all ties failed at every tested load above. At the low test speed of 10 km/hr and low load of 1,200 kg, tested tires did not blowout after testing for 24 hours, except for tire brand E. The load and speed test are important for determining the finite life of the tire. The medium-to-high speed and load are more suitable for this testing because there were blowout at all conditions. The higher speed and load increases the frequency and amplitude of cyclic stress in rubber. These cause a higher strain rate and strain energy density in the section of solid tires. At low speed and low load, the heat generation and heat conduction are steady and the temperature rise in the rubber is not high enough to generate sufficient quantities of a volatile decomposition in the rubber compound (Gent *et al.*, 1998).

Figure 3. shows the average service life of the reference group at 10, 15 and 20 km/hr. The vertical axis is load test whereas the horizontal axis is service life. Each point on the plot is obtained from the mean value of service life among the five brands compared at the same load and speed. These plots are used to compare with other tires for evaluating the quality.

3.2 Evaluation

A group of low quality solid tires coded as L1, L2, L3, L4 and L5 was intentionally produced by over and under curing of rubber. They were tested only at of 2,000 kg and 20 km/hr due to two reasons; 1) the limit number of the acquired tire and 2) a sure blowout condition. The service life of this group is shown in Table 2. At test speed of 20 km/hr from Table 1, the minimum, mean and maximum service life line of the reference group are plotted in order to determine the range as shown in Figure 4. The service life of the low quality tires was compared to these plots.

At the testing condition of 2,000 kg and 20 km/hr, the service life of all tires in the low quality group was in between minimum and mean service life of the reference group. The

Figure 3. Mean service life of solid tires size 6.00-9 at various test speeds.

Table 2. Service life of low quality group of solid tires (L1-L5) size of 6.00-9 tested at load of 2,000 kg and speed of 20 km/hr.

Code	Service life (hr) of low quality group
L1	1.00
L2	1.08
L3	0.78
L4	0.83
L5	0.97

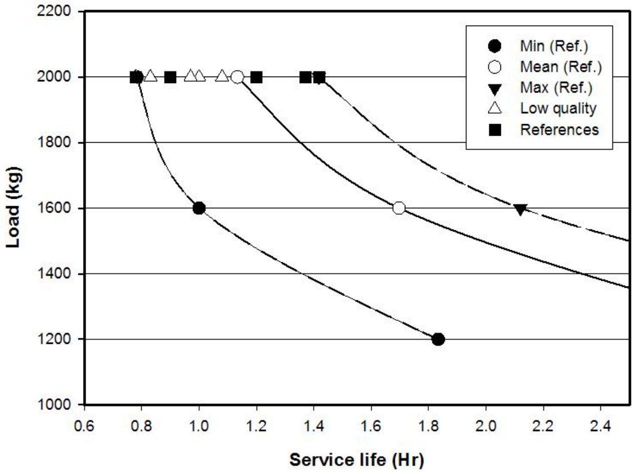

Figure 4. Service life of solid tires size 6.00-9 at test speed of 20 km/hr.

mean service lives were 56 minutes and 68 minutes for low quality and reference group, respectively. It was also shown that service life of all tires in the low quality group was not above the mean service life-line of the reference group. By comparing the mean reference line, it was found that good quality tires occurred about 60% of the time in the reference group and there were no good quality tires ever in the low quality group.

Further testing of low quality tires should be performed under other conditions such as load of 1,600 and 1,000 kg and at speeds of 10 and 15 km/hr. We were unable to do that in this study because of the limitation in producing a lot of low quality solid tires for testing and the amount of time this would entail. The testing of the low quality tires at 2,000 kg and 20 km/hr indicates the possibility of using service life to evaluate the endurance quality of solid tire.

4. Conclusions

The drum testing machine used was designed and constructed for rigidity, simplicity, low cost and the ability to test two tires simultaneously. It can be used effectively to measure the service life of a solid tire. The procedure to measure the service life is practical. In this study, the load and speed test condition are important to determine the finite service life. The medium to high speed and load is more suitable than low load and speed test condition because of the resultant blowout for all tested tires. The evaluation of quality is demonstrated by comparing mean service life plots between the standard reference group and the low quality group of solid tires. It was found that there is a possibility of using service life to evaluate the quality of solid tire. In order to improve the reliability of this proposed evaluation, further studies are needed and more tests designed to compare low quality tires at other load and speed conditions and establish criteria for testing and classifying solid tires.

Acknowledgements

This research was financially supported by the Thailand Research Fund (TRF), fiscal year 2007 and Industrial Council of Thailand. The Department of Mechanical Engineering and the Department of Electrical Engineering, Faculty of Engineering, Prince of Songkla University, are gratefully acknowledged for other support.

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