Determining an acceleration factor for a metering pump used in a polyurethane injection machine

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ABSTRACT

A metering pump for a polyurethane injection machine is used to mix urethane with isocyanate (a plasticizer) and polyol (the raw material of polyurethane). The metering pump has typically used a piston-type hydraulic pump, which is a high-pressure mixed type; the materials are mixed with a constant flow by the mixing head device, which supplies the fluid flow through the pipelines. In terms of supplying the flow to the devices, the role of the metering pump is important in supplying a constant flow. This study focused on determining the acceleration factors (AF) via the accelerated life test method, as a life test under normal operating conditions takes more than five years to carry out. This research selected the stress factor that accelerated the main failure modes of the polyurethane injection metering pump, and the adopted acceleration model was the inverse power law. After selecting the acceleration factor and the model, the acceleration test was performed with an acceleration pressure of 21 MPa, as the operating pressure of the metering pump under the surveyed field operation conditions was 15 MPa.

1. INTRODUCTION

Polyurethane (PU) composites have become an accepted alternative in the infrastructure industry, particularly for applications that require high strength-to-weight ratios and durability. Polyurethanes have several factors that make them desirable polymers for composites. PU systems are a low-cost and high-performance polymer. Polyurethane durability contributes significantly to the long lifetime of many products(Nicholas, Moharned, Dhaliwai, Anadan, and Chandrashekhara, 2016). Mane, Vhandra, Sharma, Chavan, Manjunath and Patel (2017) conducted an experimental study to observe the change in the impact response of rigid polyurethane foam at different strain rates. Kaliafetis and Costopoulos (1995) studied the static and dynamic characteristics of an axial piston variable displacement pump with a pressure regulator. The governing equations of the complete pump unit were derived, and the analysis was performed by computer simulation, which determined the significant parameters of the complete pump complete unit. Bergada (2012) focused on understanding the flow losses and the resulting flow/pressure dynamics in a piston pump. Initially, equations to evaluate leakages in all piston pump gaps were presented and tested against numerical models, and the equations were later linked to determine the general pressure/flow pump dynamic characteristics. The model also provided the temporal pressure in each piston/cylinder chamber and the temporal leakage in all pump clearances. Kumar, Bergada, and Watton (2013) presented the static and dynamic characteristics of a piston pump slipper with a groove. Three-dimensional Navier Stokes equations in the cylindrical coordinates have been applied to the slipper/plate gap, including the groove.

Lee, Kim, Yoo, and Park (2006) proposed a new accelerated life test method for the hydraulic pumps used in vehicles, which have multiple alternating loads. To determine the lifetime of a hydraulic pump under given field conditions with respect to the duty cycle, the equivalent load and speed of the unit have to be determined. Angadi et all (2009) studied the reliability of the solenoid valve used in automobile transmissions through a joint theoretical and experimental approach. The goal of this study was to use accelerated life tests to characterize solenoid valve failure and correlate the results to new comprehensive finite element models. Pohl and Hermanns (1997) found that the fuel degrades over time depending on the system temperature, the tank volume, and the flow rates in the fuel supply system for a conventional household oil heating system. The analysis showed that the typical variances in the characteristic parameters led to a significant distribution in the failure time. Furthermore, the functional relation between the tank volume as a stress factor and the failure time was described.

The polyurethane foaming machine consisted of the metering pump, which was a bent axis hydraulic pump, as well as the tank, flowmeters, automatic valves, and mixing head. The key component of this system is the metering pump, which must supply a constant flow to the mixing head, so it should have good reliability characteristics during the lifecycle of the system.

The polyurethane foaming machine metering pump is a piston pump that delivers the polyurethane to the foaming machine. The metering pump is an essential component in producing high-quality products because it must provide a constant flow without variation, as the polyurethane must be mixed with polyol and isocyanate at the same flow rate.

This study performed a failure and mechanism analysis after researching the field conditions because the polyurethane metering pump must have excellent performance characteristics to ensure durability. Also, based on the failure analysis, this study calculated a no failure life test time after selecting the shape parameter, the quantity of the test sample, and the warranty time. Finally, an acceleration factor for the accelerated life test was considered to reduce the durability test time because the life test can take over 10,000 hours about 3 years, which makes it practically difficult to perform the test.

Table 1 Specification of metering hydraulic pump

Product name	Metering hydraulic pump
Type	Bent axis
Rated pressure	21.0 MPa
Flow	22 mL/min
Testing temp	(20 ~ 35) ℃
Fluid	ISO VG (32-46)

Figure 1 Photo of the polyurethane foaming machine and metering pump

2. FAILURE MODE AND MECHANISM ANALYSIS

The main components of the metering pump, which is a bent axis hydraulic pump, are the housing, piston assembly, cylinder block, valve plate, handle, relief valve, and shaft. Table 1 presents the specifications for the metering hydraulic pump. The failure mode, mechanism, and function of the valve are shown in Table 2. The main failure mode of the metering pump is the wear of the valve plate.

Table 2 Failure modes and mechanism analysis

Primary components	Failure modes	Failure mechanisms
Housing	Looseness, deformation	Overload, fatigue
	Corrosion	Moisture and salt
Piston assembly	Wear	Dirt particles, shortage of oil
Cylinder block	Wear	Fatigue, dirt particles
	Fracture	Overload, fatigue
Valve plate	Wear	Fatigue
	Surface damage	Overload, vibration
Handle	Wear	Fatigue
	Stick, looseness	Overload, vibration
Relief valve	Fracture	Fatigue, dirt particles
	Deformation	Fatigue, dirt particles
	Wear	Overload, fatigue
Shaft	Wear	Overload, fatigue
	Deformation	Vibration, fatigue
Bearing	Fracture	Overload, fatigue
Spring	Fracture	Overload
	Deformation	Fatigue, dirt particles
Seals	Fracture	Overload
	Wear	Degradation, fatigue
Barry seal	Wear	Degradation, fatigue, shortage of oil

3. ACCELERATED LIFE TEST

3.1 No failure life test time

As a result of the research in the targeted industrial field, the mean warranty period for the accelerometer sensor is three years, the operating time per day is 8 hours, and the operating days per year is 365 days. The equivalent lifetime for three years is 9,000 hours. Therefore, the warranty lifetime guarantees a B_{10} life of 3,000 hours with a confidence level (CL) of 80%.

The main failure mode of the metering pump is the wear of the valve plate due to over pressure of the system; the shape parameter (β) is 3.0 [11], citing the Weibull distribution referred to by Li-Xia Yu. Finally, n=10 samples are considered:

$$t_n = B_{100p} \cdot \left[\frac{\ln(1-CL)}{n \cdot \ln(1-p)}\right]^{\frac{1}{\beta}} \quad (1)$$

$$= 9000 \cdot [\frac{\ln(1-0.7}{10\cdot(\ln(1-0.05)}]^{\frac{1}{3.0}}=11960.8$$

Here, t_n is the no failure test time, B_{100p} is the warranty lifetime, CL is 70%, n is the number of samples, unreliability p is 0.05, and the shape parameter β is 3.0.

3.2 An equation for the accelerated life test

The accelerated life test time was calculated by selecting the AFs with pressure as stress factors to accelerate the wear of the hydraulic pump. This represented the primary failure mode of the hydraulic pump because too much time was spent on the no failure life test. The adopted acceleration model used the power inverse model. The mean value of the operating conditions, namely the pressure, was 15 MPa, and the acceleration value was 21 MPa. In addition, the accelerated life test time was calculated with a total of 820 hours, with an AF of 14.76 adopted for a fatigue stress index of 8.0 (Heinz & Fred, 1997), as follows:

$$AF = \left(\frac{V_{test}}{V_{field}}\right)^m = \left(\frac{21}{15}\right)^{8.0} \approx 14.76 \tag{2}$$

This shows the AF, pressure with acceleration condition (V_{test} [MPa]), vibration with operating condition (V_{field} [MPa]), and acceleration index (m=8.0). After getting AF=14.76, the acceleration time can be calculated by the equation t_{na}, as below:

$$t_{na} = \frac{t_n}{AF} = \frac{11960.8}{14.76} = 810.4 \approx 820\ hours \tag{3}$$

4. RESULTS AND DISCUSSION: ACCELERATION FACTOR

Figure 2 shows the loading condition of the test modes, which are separated by the speed and pressure of the hydraulic pump for the excavator, the continuous rotation speed, and the repeated impulse pressure with a 5 second interval (Korea Institute of Machinery and Materials, 2008). There are two test modes in the case of the oil pump for the automobile. Figure 3(a) represents the repeated loading condition between the maximum and minimum pressure with 2 second intervals and a 3000 r/min constant rotation speed over 150 hours, and Figure 3(b) shows the pressure up to 0.7 MPa for 50 hours and 0.1 MPa for 50 hours, with 8500 r/min (KIMM, 2008). There is a general test procedure for an aircraft hydraulic pump base on the SAE standard, as shown in Figure 4 and Table 3 (SAE international, 1999). However, the test tailoring method in MIL-STD-810G must match the field conditions, and the law of thumb for the test is to use the real measurement data from the field operating conditions. The research found that the pressure, flow, and rotation speed of the hydraulic pump were the main acceleration factors for the accelerated life test. Therefore, in performing the accelerated life test in the laboratory for the hydraulic pump for polyurethane fluid, the determination of the acceleration factors and the test mode should be based on the field operating conditions.

Figure 5 presents the test mode of the hydraulic pump for polyurethane fluid. The test was performed with a loading condition of 5 minutes and an unloading condition of 10 seconds for manufacturing products such as styrofoams, sandwich panels, steel facing, and sliding panels. Figure 6 shows photos of the failure modes of the hydraulic pump, which were seal leakage of the shaft and the flange on the pump housing due to the impulse pressure.

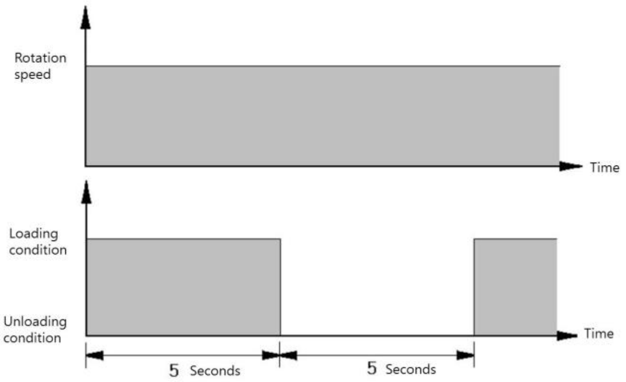
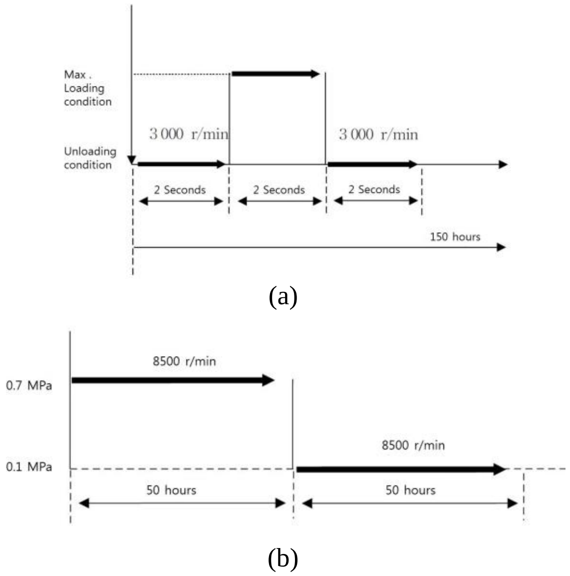


Figure 2 Hydraulic pump test mode for forklift



(a)

(b)

Figure 3 Hydraulic pump test mode for automobile oil pump

Figure 6(a) shows the leakage coming out from the shaft after the acceleration life test due to the cumulative damage of the seal surface. Figure 6(b) shows the leakage between the surface of the pump housing and the seal of the output pressure flange.

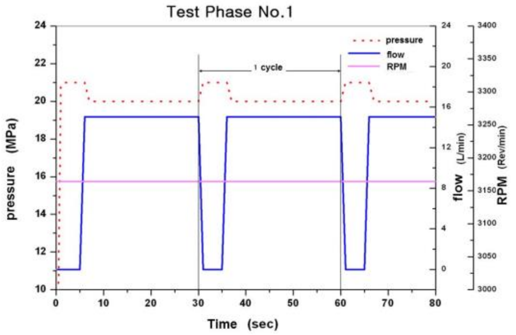


Figure 4 One of the test modes in the SAE durability test condition

The reason for the leakage, as shown in Figure 6(b), is the fatigue damage and deformation due to the impulse pressure, as shown in Figure 5.

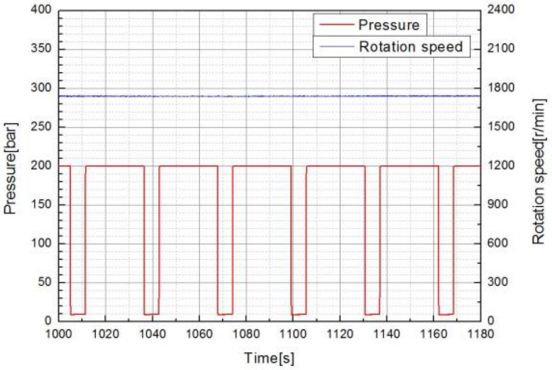
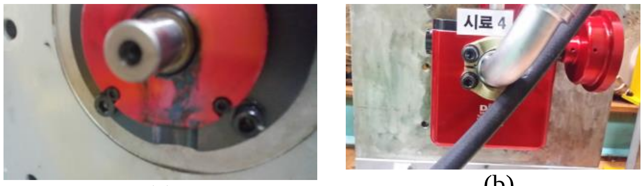


Figure 5 Metering pump test mode varies with the pressure and constant rotation speed



(a) (b)

Figure 6 Photos of the failure modes and leakages

5. CONCLUSION

It is important to select the correct acceleration factors for performing the accelerated life test. Otherwise, it will be difficult to perform the reappearance test, which makes failure same as field operating condition. Also, selecting the acceleration factors for the test can be affected by the life of the products due to the difference in the cumulative damage. Therefore, this study performed the test and selected the pressure as the acceleration factor for the hydraulic pump for polyurethane. The test mode of the pump was 5 minutes for the loading condition and 10 seconds for the unloading condition, which were the most common conditions for the hydraulic pump.

Future work should focus on predicting the lifetime based on cumulative damage under the test mode, as referred to in the figures.

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