Fatigue life prediction of SUS sleeve in Laser-printer fuser

Sun Ho Park, TaeHan Kim; S-Printing Solution Co, Ltd; Suwon, South Korea

Abstract

One of the most frequent durability issues in laser printer system is the failure of thin metal sleeve in the fuser assembly. In order to ensure the reliability of the laser printer, it is important to predict the failure of the thin metal sleeve in the fuser assembly.

In this study, the method to predict fatigue life of fuser SUS sleeve with 3D dynamic simulation and fatigue simulation using ABAQUS and FEMFAT is introduced. Fatigue property of fuser SUS sleeve is correlated with MIT folding endurance test results and safety factor is calculated to endure the product life specification.

Introduction

Fusing is the last stage of printing process in laser printer. As the paper passes through nip area located inside fuser, the toner powder on paper is fused and bonded onto paper with very high pressures and temperature up to 200℃ to complete the image. Nip area is constructed to push pressure roller onto thin metal sleeve with supporting structure inside. One of the major durability problems in the laser printer fuser is the failure of the metal sleeve. Pressure roller and fuser belt rotates continuously together to transfer paper. That makes metal sleeve of fuser belt experience a repeated bending stress history. Once a small damage or crack occurs in metal sleeve, a slight defect shows in the printing image and this small crack gets bigger and fuser metal sleeve tears apart eventually as shown.

Since it is very difficult to detect a small crack on fuser metal sleeve in the early stage, users find out the fuser problem after the failure of metal sleeve such as figure 1 in most cases. Even though a small crack is detected before the failure of metal sleeve, service technician should exchange the fuser assembly because users cannot replace fuser belt. That means the failure of fuser metal sleeve will raise repair cost, so it is very important to ensure the reliability of fuser metal sleeve for the profitability.

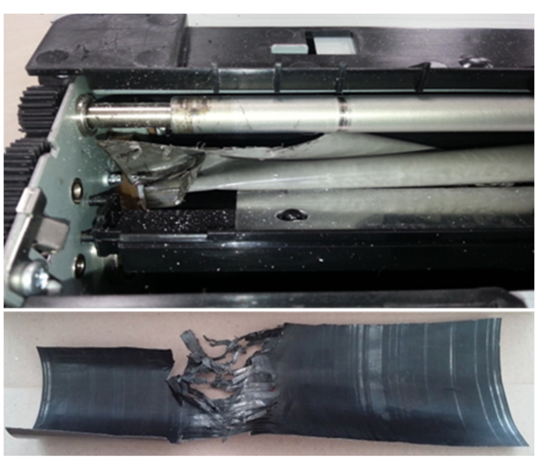

Figure 1 Failure of fuser metal sleeve

Fuser Structure

General type of fuser includes a pair of rollers. One is the heating roller for generating heat to be applied to toner, and the other is pressure roller for applying pressure. These days belt-type fuser that applies thin belt instead of heating roller is used for high-speed printer like figure 2.

In order to transfer heat and pressure to toner, paper passes through fuser nip area with high pressure and temperature. Fuser nip area is made between pressure roller and fuser belt with nip support structure, such as plate-nip, holder inner and support bracket. Pressure roller is pushed onto fuser belt with springs at the both end of fuser structure.

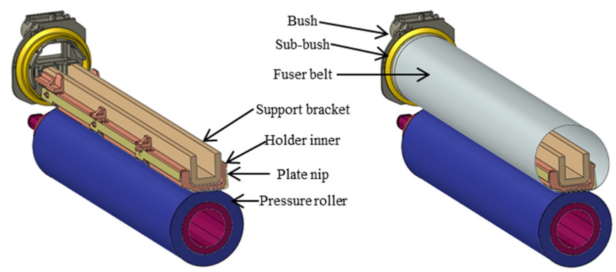

Figure 2 Structure of belt-type fuser

In the case of belt-type fuser, there is a disadvantage that crack may occur in the metal sleeve due to repeated rotation of the belt. Fuser belt is made up of 3 layers as figure 3; metal sleeve layer as a substrate, liquid silicone rubber (LSR) layer as a elastic layer on the metal sleeve layer, and Perfluoroalkoxy (PFA) layer as a release layer.

SUS is used for metal sleeve due to high heat capacity and wear-resistance characteristics. SUS sleeve maintains the stiffness of the fuser belt and resists abrasion, but the thickness of SUS sleeve is less than about 40 ㎛ to ensure the proper life against the bending stress caused by continuous rotation.

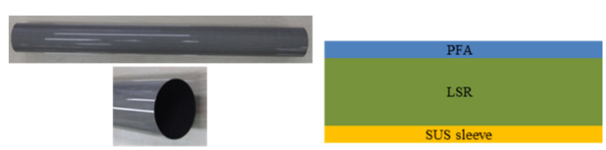

Figure 3 Structure of fuser belt

Fuser simulation

2D & 3D static simulation

The fuser belt is continuously rotating with pressure roller and experiences bending stress, which may cause damage due to fatigue on SUS sleeve. 2D static simulation as shown in figure 4 is used to check the nip size, pressure distribution and bending stress level of SUS sleeve.

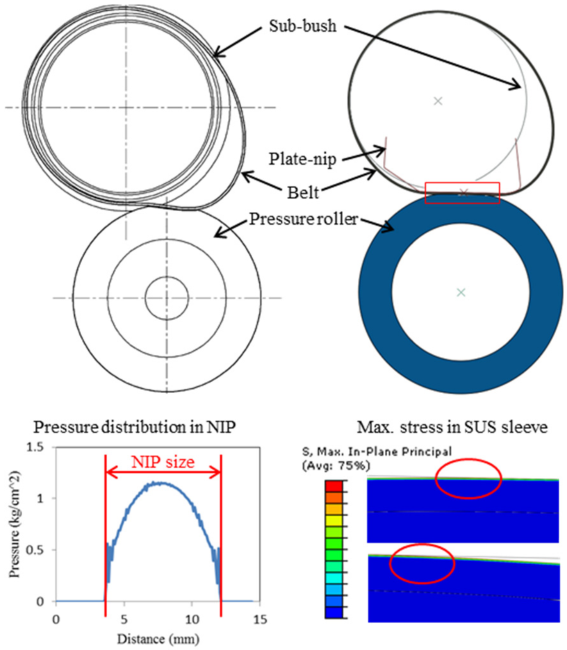

Figure 4 2D static simulation result

In order to solve paper wrinkle issue when paper passes through nip area, crown shape is applied on the outer diameter of pressure roller and holder inner surface. Nip surface on the plate-nip in axial direction is not completely flat because of the deformation of nip support structure as shown in figure 5 by concentrated force on both bushes at the end of nip support structure. That means 3D belt profile in axial direction of the belt is not quite same with 2D belt profile. Therefore, it is necessary to perform 3D static simulation considering the deformation of nip support structure and pressure roller with crown in order to check the stress distribution of SUS sleeve.

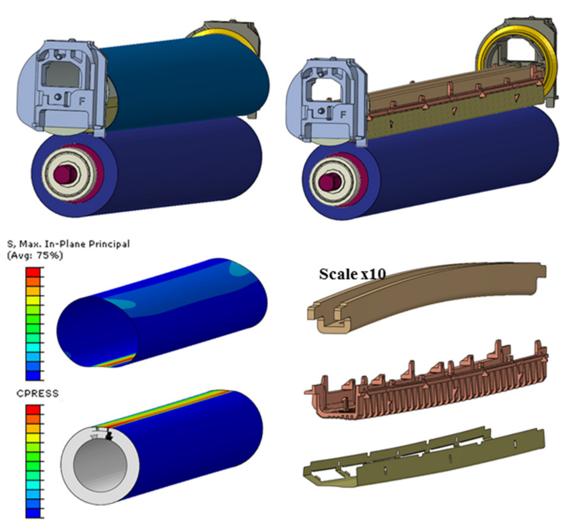

Figure 5 3D static simulation result

3D dynamic simulation

In order to reduce calculation time and resources, 3D belt dynamic simulation is performed with the deformed shape of nip support structure from 3D static simulation. The fuser belt rotates with the pressure roller, so there is a friction between the fuser belt and nip support structure such as plate-nip. The effect of wear on the failure of SUS sleeve is disregarded for now because the lubricant inside the fuser belt and the wear-resistance characteristic of SUS.

Although the circular fuser belt maintains the profile deformed by the plate-nip and sub-bush, the plate-nip and sub-bush do not pull the fuser belt tightly to prevent excessive stress on SUS sleeve, so there is a certain gap between the fuser belt and parts inside the belt. Because of gap between the fuser belt and supporting parts such as plate-nip and sub-bush, the stationary belt profile is different from the belt profile when the belt rotates as shown in figure 6.

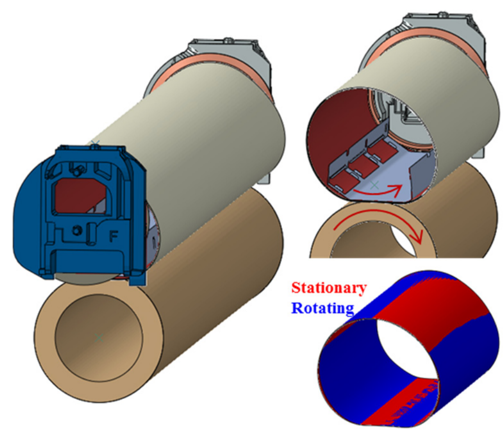

Figure 6 3D dynamic simulation result

Fatigue and life prediction of SUS sleeve

Fatigue property of SUS sleeve

In this work, 3D dynamic simulation and fatigue simulation are performed to ensure the reliability and robustness of SUS sleeve in fuser against continuous bending stress. In order to reduce bending stress on SUS sleeve, thickness of SUS sleeve must be very small. Due to extremely large thickness reduction, the manufacturing processes from base plate to SUS sleeve are very complicated like figure 7.

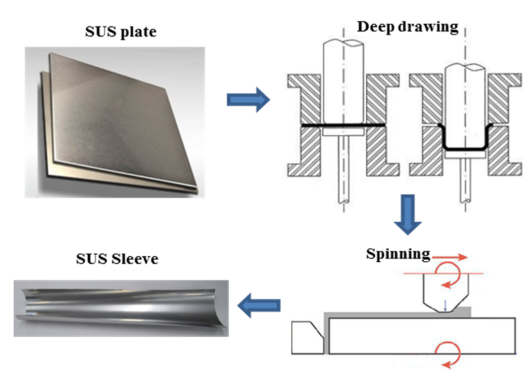

Figure 7 Manufacturing processes of SUS sleeve

There is a strong correlation between fatigue strength and tensile strength[1][2]. Wöhler analyzed the relationship between fatigue strength and static characteristics of the ferrous metals[3]. It was shown that the relationship between the fatigue limit σ_R and ultimate strength σ_u established like

$$\sigma_R = (0.35 - 0.6)\sigma_u \tag{1}$$

Ultimate strength, hardness and fatigue limit of metastable stainless steels such as SUS 304 are increased due to plastic deformation during cold working. These properties are mainly attributed to the deformation induced martensitic transformation [4][5] [6].

SUS 304 plate before manufacturing process for SUS sleeve is typical 18Cr-8Ni austenitic stainless steel. The mechanical properties of SUS sleeve such as tensile strength, hardness and fatigue property are changed very much due to the effect of strain-hardening during manufacturing processes.

As shown in table 1, tensile strength and hardness of SUS sleeve is about 2.6 times higher than that of SUS base material.

	Elastic modulus	Tensile strength	Hardness (Micro-Vickers)
SUS 304 plate	221 GPa	640 MPa	180
SUS sleeve	224 GPa	1690 MPa	464

Table 1. Mechanical property of SUS plate and SUS sleeve

In order to acquire the S-N curve of SUS sleeve, the standard tensile fatigue test under R=0 test condition with the specimens from SUS 304 base plate before manufacturing processes is performed, because small thickness and cylindrical shape of SUS sleeve makes very difficult to perform standard tensile fatigue test.

	Tensile strength	Fatigue strength
SUS 304 plate	640 MPa	192 MPa
SUS sleeve	1690 MPa	507 MPa

Table 2 Fatigue strength of SUS sleeve

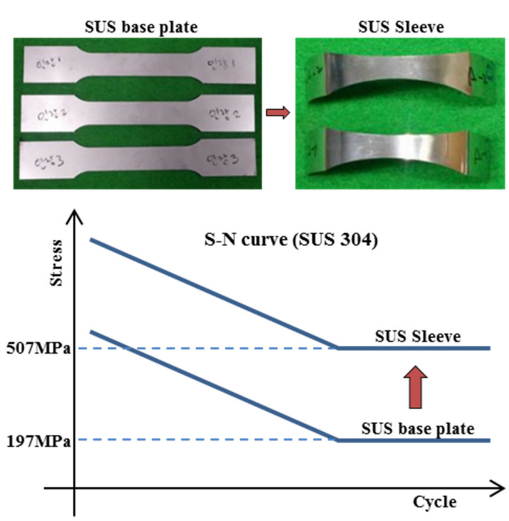

Figure 8 S/N curve of base material and SUS sleeve

Fatigue material property of SUS sleeve is calculated with S-N curve of base material. The ratio of fatigue strength to tensile strength in SUS 304 base material is 0.3. Fatigue strength of SUS sleeve is calculated with the ratio of fatigue strength to tensile strength of SUS 304 base material as shown as table 2, and the slope in S-N curve of SUS sleeve is assumed to be same as that of SUS plate as shown as figure 8.

Fatigue life and safety factor calculation of Fuser belt

In order to check the fatigue material property of SUS sleeve MIT folding tests with various bending shaft diameter are performed instead of tensile fatigue test. MIT folding tests for each bending shaft diameter are repeated 10 times.

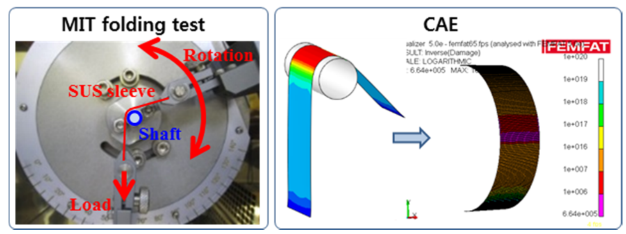

Figure 9 Comparison of failure cycle in MIT folding test with SUS sleeve

The fatigue material property for CAE is correlated with MIT folding test result with SUS sleeve to compare failure cycle from MIT folding test for several bending shaft diameter as shown as figure 9.

Life prediction of SUS sleeve with CAE is performed with Dynamic 3D simulation with abaqus version 2016 and fatigue simulation with FEMFAT version 5.2.

Bending shaft diameter	Failure cycle	
	TEST	CAE
5.0mm	14,978	14,954
6.0mm	40,097	47,619
7.0mm	62,366	138,581
7.5mm	203,822	205,212

Table 3 Correlation result with Test and CAE

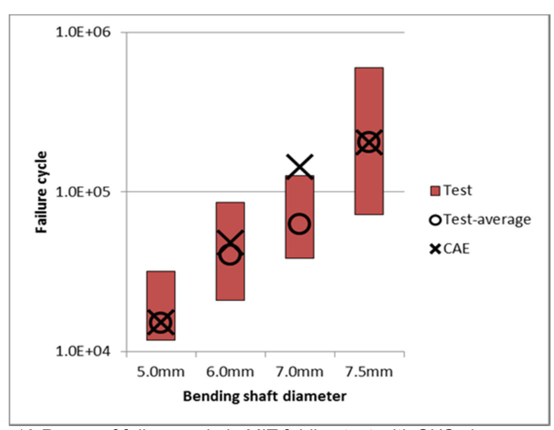

Figure 10 Range of failure cycle in MIT folding test with SUS sleeve

Correlation result between MIT folding test and CAE is shown in table 3.

Even though fatigue life of SUS sleeve from CAE is larger than the expected failure cycle from product life specification, it is impossible to endure product life due to large dispersion in MIT folding test result. Safety margin is set up with the minimum range of MIT folding test as shown in figure 10. According to the safety margin from minimum range of MIT folding test result, the safety factor from fatigue simulation should exceed 1.3.

3D dynamic simulation and fatigue simulation is performed with the laser printer fuser model currently on sale. Calculated safe factor is 1.74 with the expected failure cycle of SUS sleeve from product specification as shown in figure 11. That means this product has enough safety margin for the expected life.

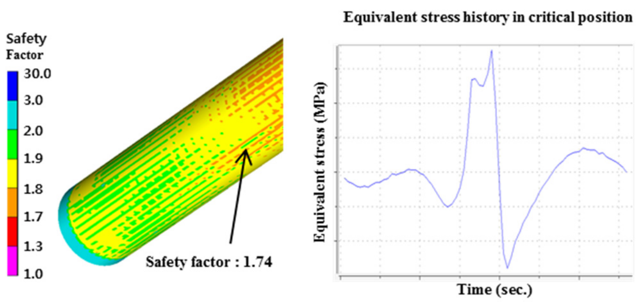

Figure 11 Safety factor calculation result and equivalent stress history in critical position

Conclusion

In order to ensure the reliability of laser printer fuser for product life specification, safety factor calculation method with 3D dynamic simulation and fatigue simulation is proposed. S-N curve of SUS sleeve is acquired from S-N curve of base material and the effect of strain-hardening during manufacturing processes. Fatigue material property of SUS sleeve is correlated and safety margin is set up with MIT folding test results.

References

[1] P.G. Forrest, Fatigue of Metals, Pergamon Press, Oxford, 1962

[2] J.C. Pang et al, General relation between tensile strength and fatigue strength of metallic materials, Material Science & Engineering A 564, 2013, p331-341

[3] L. Tóth, S. Ya. Yarema, Formation of the science of fatigue of metals . Part1, Materials Science 42, 2006, p673-680

[4] M. Nakajima et al, Effect of strain-induced martensitic transformation on fatigue behavior of type 304 stainless steel, Procedia Engineering 2, 2010, p323-330

[5] H-J Christ et al, Effect of deformation-induced martensite on the fatigue behavior of metastable austenitic stainless steels, Proceedings of the 12th international conference on fracture, 2009

[6] C. Müller-Bollenhagen et al, Adjusting the very high cycle fatigue properties of a metastable austenitic stainless steel by means of the martensite content, Procedia Engineering 2, 2010, p1663-1672

[7] Kwang-Soo Lee, Ji-Ho Song, Estimation methods for strain-life fatigue properties from hardness, International Journal of Fatigue 28, 2006, p386-400

[8] FEMFAT theory manual

Author Biography

Sun ho Park received his BS & MS in mechanical engineering from YONSEI University (2004). Since then he worked in Safety CAE team at GM Korea and Body CAE team at Renault Samsung Motors, and has worked in the System architecture Lab at S-Printing Solution, His work has focused on the structural analysis and fatigue issues of mechanical parts in laser printer system.