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journal or publication title	International Journal of Modern Physics B
volume	35
number	14n16
page range	2140024
year	2021-05-14
URL	http://hdl.handle.net/10228/00008846

doi: <https://doi.org/10.1142/S0217979221400245>

FATIGUE STRENGTH IMPROVEMENT OF ROLLER CHAIN BY PRESS FITTING BETWEEN PIN AND PLATE

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Received Day Month Day

Revised Day Month Day

To improve the fatigue strength of the roller chain, the fatigue test is conducted by varying the press-fitting ratio between the pin and the holed plate. To model what occurs in a chain under load, a single plate specimen is prepared by press-fitting two pins into two holes at the ends of the plate. The FEM analysis is performed to obtain the stress amplitude and the average stress. The results, in both cases demonstrate that the fatigue strength is improved by the press-fit between the pin and the hole. The fatigue improvement mechanism is discussed based on the stress analysis.

Keywords: Roller chain; Fatigue test; Fatigue strength; FEM; Stress; Fretting fatigue.

1. Introduction

Figure 1 shows the schematic illustration of the roller chain including five components. Roller chains are commonly used to transmit mechanical power in industrial machineries including conveyors, motorcycles, bicycles, and so forth. However, sometimes fatigue failure has been observed at the bush and/or pin as well as the link plate hole during the operation. The previous 2D thick cylinder modelling showed that the press-fitting pins and bushes into the plate improves the fatigue limit although pin bending deformation was not considered¹. Recent 3D FEM analysis discussed the shrink-fitted stress without showing fatigue strength². Considering those situations, the authors previously analyzed the total structure in Fig. 1 of the roller chain by comparing the critical portions of each component³. The results showed that the maximum stress appears at the hole edge of the plate due to the press-fitting of the pin and the bush into the plate.

This paper will focus on the effect of the press-fitting ratio on the fatigue strength which was not analyzed in the previous study. It should be noted that the fatigue strength of the total roller chain in Fig. 1 is largely affected by the manufacturing precision of each component. To clarify the press-fitting effect on the fatigue strength, in this study, the plate specimen is used as the specimen as shown in Fig. 2 for the fatigue test. In Fig. 2, two pins

are press-fitted into the plate holes of the plate specimen. The FEM analysis is also performed to explain the fatigue test results.

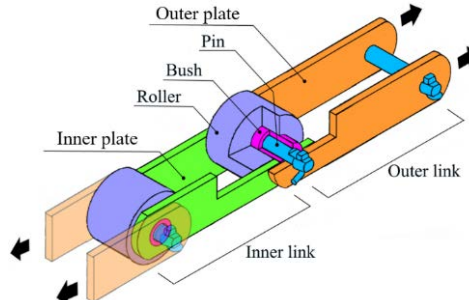


Fig. 1. Basic structures and loads of the roller chain.

2. Experimental method and Analytical method

Figure 2 is an illustration of the specimen used for the fatigue test. The pin is press-fitted into the plate hole whose diameter d is smaller than the pin's outer diameter $D=15.8\text{mm}$ by the amount δ . In other words, $\delta = (D - d)$. Two conditions, $\delta=0$ of press-fitting ratio $\delta/D=0$ and $\delta=0.04\text{mm}$ of $\delta/D=2.5\times 10^{-3}$, are prepared. Considering loading/unloading in real roller chains during the operation, the fatigue test is conducted under pulsating cyclic tension. The cyclic load F for the fatigue test is denoted by $F=F_{min} \sim F_{max}$. Then, the minimum load F_{min} is fixed as $F_{min}=3\text{kN}$ and the maximum load F_{max} is set as $F_{max}=25\sim 80\text{kN}$. Here, the nominal stress σ_n is defined as the average stress at the minimum cross section $\sigma_n=F/A$ as shown in Fig. 2(b). Then, the minimum nominal stress is $\sigma_{min}=13\text{MPa}$ at $F_{min}=3\text{kN}$ and the maximum nominal stress $\sigma_{max}=110\sim 352\text{MPa}$ at $F_{max}=25\sim 80\text{kN}$. The fatigue limit is evaluated at the number of cycles $N_f=10^7$.

For the analytical method, three-dimensional elastic-plastic analysis is performed by using finite element method software MSC.MARC 2012 with hexahedral 8-node isoparametric element. The direct constraint method is used for the contact analysis under the nominal stress $\sigma_{min}=13\text{MPa}$ and $\sigma_{max}=286\text{MPa}$. At the hole edge $\theta=90^\circ$ is analyzed as shown in Fig. 2 because the fatigue fracture most often occurs in the cross section of the link plate that is perpendicular to the applied load in real roller chains. The fatigue test described in section 3.1, shows clearly that the fatigue limit of the components at $\delta/D=2.5\times 10^{-3}$ is significantly higher compared to the fatigue limit at $\delta/D=0$. In this experiment, a relatively smaller $\delta/D=2.5\times 10^{-3}$ is chosen since a larger press-fitting ratio may cause other types of failures.

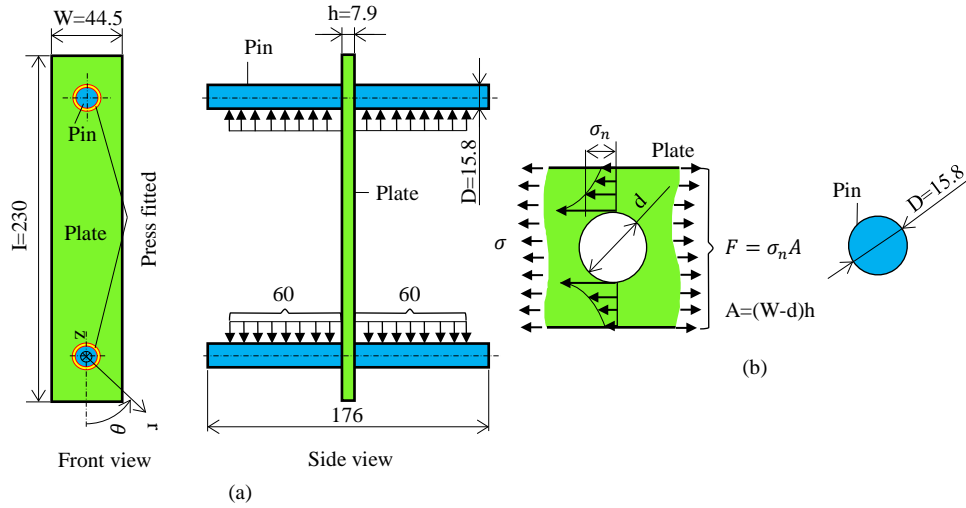


Fig. 2. Illustration of fatigue test specimen consisting of pin and plate (unit: mm): (a) Fatigue test specimen; (b) Definition for nominal stress σ_n .

3. Experimental results and Analytical results

3.1. Experimental results and discussion

Figure 3 shows S-N diagram for $\delta/D=0$ and $\delta/D=2.5 \times 10^{-3}$. The fatigue limit σ_w is determined as $\sigma_w = 50\text{MPa}$ at $\delta/D=0$ and $\sigma_w = 125\text{MPa}$ at $\delta/D=2.5 \times 10^{-3}$. σ_w at $\delta/D=2.5 \times 10^{-3}$ is more than twice σ_w at $\delta/D=0$. It is reasonable to conclude therefore that press-fitting is an effective method to improve the fatigue limit for roller chains.

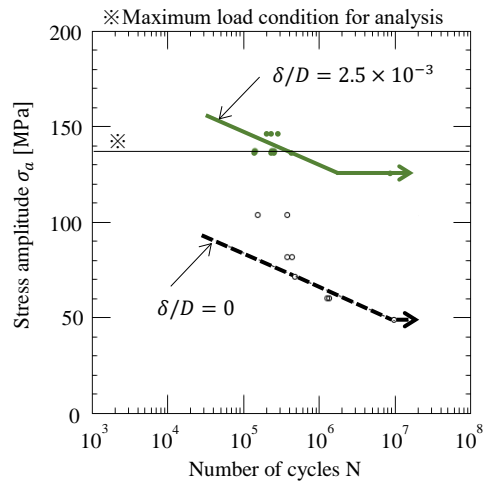


Fig. 3. S-N diagram for test pieces in Fig. 2.

3.2. Analytical results and discussion

Table 1 shows the minimum stress $\sigma_{\theta \min}$ at $F=F_{\min}$ and the maximum stress $\sigma_{\theta \max}$ at $F=F_{\max}$ under $\delta/D=0$ and $\delta/D=2.5 \times 10^{-3}$. Those stresses appear at $\theta=90^\circ$ as shown in Fig. 2 at the hole edges. In Table 1, the mean stress $\sigma_{\theta m}$ is defined as $\sigma_{\theta m}=(\sigma_{\theta \max} + \sigma_{\theta \min})/2$, and the stress amplitude $\sigma_{\theta a}$ is defined as $\sigma_{\theta a}=(\sigma_{\theta \max} - \sigma_{\theta \min})/2$.

$\sigma_{\theta \min}$ at $\delta/D=2.5 \times 10^{-3}$ is larger than $\sigma_{\theta \min}$ at $\delta/D=0$ because $\sigma_{\theta \min}$ increase by press-fitting and the external force $F=F_{\min} \cong 0$ is negligibly small. Instead, $\sigma_{\theta \max}$ at $\delta/D=2.5 \times 10^{-3}$ is smaller than $\sigma_{\theta \max}$ at $\delta/D=0$ because of the effect of external force $F=F_{\max}$. Compared to $\delta/D=0$, due the shrink fitting $\delta/D=2.5 \times 10^{-3}$, the external force effect becomes smaller after the shrink fitting. This is the reason why $\sigma_{\theta \max}$ when $\delta/D=2.5 \times 10^{-3}$ is smaller than $\sigma_{\theta \max}$ when $\delta/D=0$ under $F=F_{\max}$.

$\sigma_{\theta \min}$ at $\delta/D=2.5 \times 10^{-3}$ is larger than $\sigma_{\theta \min}$ at $\delta/D=0$ and $\sigma_{\theta \max}$ at $\delta/D=2.5 \times 10^{-3}$ is smaller than $\sigma_{\theta \max}$ at $\delta/D=0$. Therefore, $\sigma_{\theta a}$ at $\delta/D=2.5 \times 10^{-3}$ is smaller than $\sigma_{\theta a}$ at $\delta/D=0$ and the fatigue strength can be improved.

Table 1. Maximum stress $\sigma_{\theta \max}$ and minimum stress $\sigma_{\theta \min}$, mean stress $\sigma_{\theta m}$ and stress amplitude $\sigma_{\theta a}$ for Plate at $\theta=90^\circ$ [MPa].

$\delta/D [\times 10^{-3}]$	$\sigma_{\theta \min}$ at $F=F_{\min}$	$\sigma_{\theta \max}$ at $F=F_{\max}$	$\sigma_{\theta m}$	$\sigma_{\theta a}$
0	34	608	321	287
2.5	288	470	379	91

4. Conclusions

This study focused on the strength of the plate since the fatigue fracture in real roller chain often occurs at the edge of the pitch hole during the operation. The effect of the press-fitting ratio between the pin and the plate hole upon the fatigue strength was discussed for $\delta/D=0$ and $\delta/D=2.5 \times 10^{-3}$. A stress analysis was also performed to discuss the mechanism of fatigue strength. The conclusions can be summarized in the following way.

- (1) The experimental results showed that the fatigue limit at $\delta/D=2.5 \times 10^{-3}$ was more than twice as much as at $\delta/D=0$.
- (2) The FEM analysis showed that due to the press-fitting $\sigma_{\theta a}$ at $\delta/D=2.5 \times 10^{-3}$ becomes smaller than $\sigma_{\theta a}$ at $\delta/D=0$. This is the reason why the fatigue strength can be improved by the press-fitting.

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