STUDY OF CHANGE IN MICROSTRUCTURE OF STEEL SURFACE SUBJECTED TO CYCLIC FATIGUE LOADING

Yokohama National University Student Member ○Aleena Saleem
Yokohama National University Regular Member Hiroshi Tamura
Yokohama National University Fellow Member Hiroshi Katsuchi
Yokohama National University Fellow Member Hitoshi Yamada

1. INTRODUCTION

Damage due to the low cycle fatigue is one of the most dominant factors affecting steel structures under extreme loading conditions (Natdanai et al. 2016). Large plastic strain occurs at the local areas of steel member including bridge piers, connections and core of buckling restrained braces etc., leading to the reduction in their earthquake-resistant capacity. Various models have been developed to predict the life of steel structures under high amplitude loading. However, Further experimentation is needed to cover various conditions of steel structures i.e., surface treatments, steel properties, strain amplitude and strain rate. It can enhance the accuracy of predicting the low cycle fatigue.

This paper analyses the change in geometry of steel surface subjected to cyclic loading under the influence of various surface treatments and steel grades by focusing on spatial periodicity appearance. The process of wrinkle formation is emphasized in this research to show its relevance with crack occurrence. *Mountains-Map* software is used to qualitatively analyze surface contours at the start and end of loading cycles. Two processed surfaces, one mechanically polished and other blasted are compared. Power spectral density (PSD) analysis is performed and 3D roughness parameters are evaluated. Deformed shape of specimen and the appearance of wrinkles at 30.5cy. and 12.5cy. for mechanically polished and blasted surfaces are shown in Fig. 1.

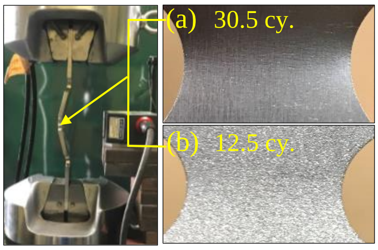

Fig. 1: Deformed shape of specimen & appearance of wrinkles

2. TESTING SPECIMEN AND EXPERIMENTATION DETAILS

Fig. 2 shows the dimensions of steel specimen consisting of arc-shaped notches. Linear displacement-controlled loading of 5mm is applied on specimens. Measurements are made at the middle notch (A) because of having no contact with side notches. To eliminate the effect of loading jig and to produce maximum strain at the center of observation surface, notched shape specimen has been selected. Specimens are named as FM-40-5S and FB-49-5S according to the type of surface treatment, steel grade and imposed displacement as in Table 1. FM-40-5S and FB-49-5S were loaded up to 30.5 and 12.5 cycles respectively, until visible macroscopic surface changes occurred. Plastic strain is evaluated from measurement results of surface geometry obtained by laser displacement meter. Fig. 3 shows the history of longitudinal plastic strain for both specimens. For bending strain, radius of curvature at (A) is calculated; however, axial strain and the effect of poison's ratio are ignored. Maximum strains of 18.73% and 17.97% are observed for FM-40-5S and FB-49-5S, respectively.

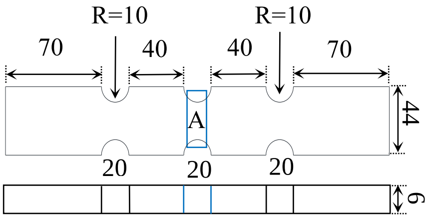

Fig. 2: Specimen geometry (units: mm)

Table 1: Conditions of specimens

Specimen	Steel Type	Surface Preparation
FM-40-5S	SM400	Mechanical Polishing
FB-49-5S	SM490	Blasting

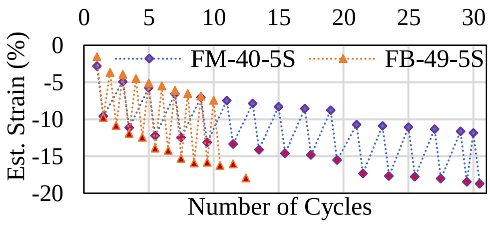

Fig. 3: Strain history

3. RESULTS AND DISCUSSION

Laser scanner (LJV-7080, KEYENCE) was used to measure the surface topography. Fig. 4 illustrates the digital microscopic (DM) images, three dimensional (3D) topographic images and average PSD plots for both specimens. Gradations in the images show the surface height. Considering polished surface, Fig. 4(a) and (e) shows regular persistent slip markings (PSMs) formed along the polishing direction consisting of intrusions and extrusions and uniform surface topography at 0.5 cy. Fig. 4(b) and (f) consists of DM and topographic images illustrating the formation of plastic wrinkles in the valley of ridges at 30.5 cy before the occurrence of cracks. Periodic mountains and valleys appeared along x-axis. Similarly, considering blasted surface, Fig. 4(c) and (d) exhibits SEM images at 0.5 and 12.5 cys., consisting of craters of collided white particles with obvious pits formed as a result of blasting treatment. Particles seem to be collapsed due to chipping under cyclic loading. Fig. 4(g) and (h) consists of 3D surface texture without waviness component at 0.5 and 12.5 cys., showing no clear geometry change due to higher roughness component produced as a result of blasting treatment.

3.1. PSD Analysis

The random nature of 3D surface topography for both specimens has been analyzed using the statistical function, i.e., PSD

Keywords: Low cycle fatigue, Surface treatment, Earthquake-resistant capacity, Wrinkle formation, Power spectral density
Contact address: Department of Civil Eng., Yokohama National University, Email: aleena-saleem-ym@ynu.jp

based on Fourier analysis. Average 1-D, composite PSD curves for polished specimen along y-direction are plotted in Fig. 4(i) at 0.5 and 30.5 cys., fluctuating with respect to spatial wavelength and finally falls to zero. Clear feature is observed at a dominant spatial wavelength of 501µm and 2 clear peaks of PSD show the change in surface geometry. Further investigation of 3D topography image (Fig. 4(f)) highlights significant harmonic periodic undulations in surface with the matching wavelength. Amplitude is within the range of 9.0 to 28.9µm for polished surface as the pixel width is 2µm in both directions. Fig. 4(j) shows composite PSD curves for blasted specimen at 0.5 and 12.5 cys. with much higher PSD values. Dominant spatial wavelength of 500µm with 1 clear peak is observed. Fig. 4(h) also shows single apparent peak corresponding to the matching wavelength. Amplitude for blasted surface varies from 29.3 to 74.7µm at 0.5 and 12.5 cys. respectively. From this analysis, roughness can be considered as high frequency and short wavelength component for blasted surface, and PSD could sensitively characterize the change in geometry of surfaces produced by various treatments.

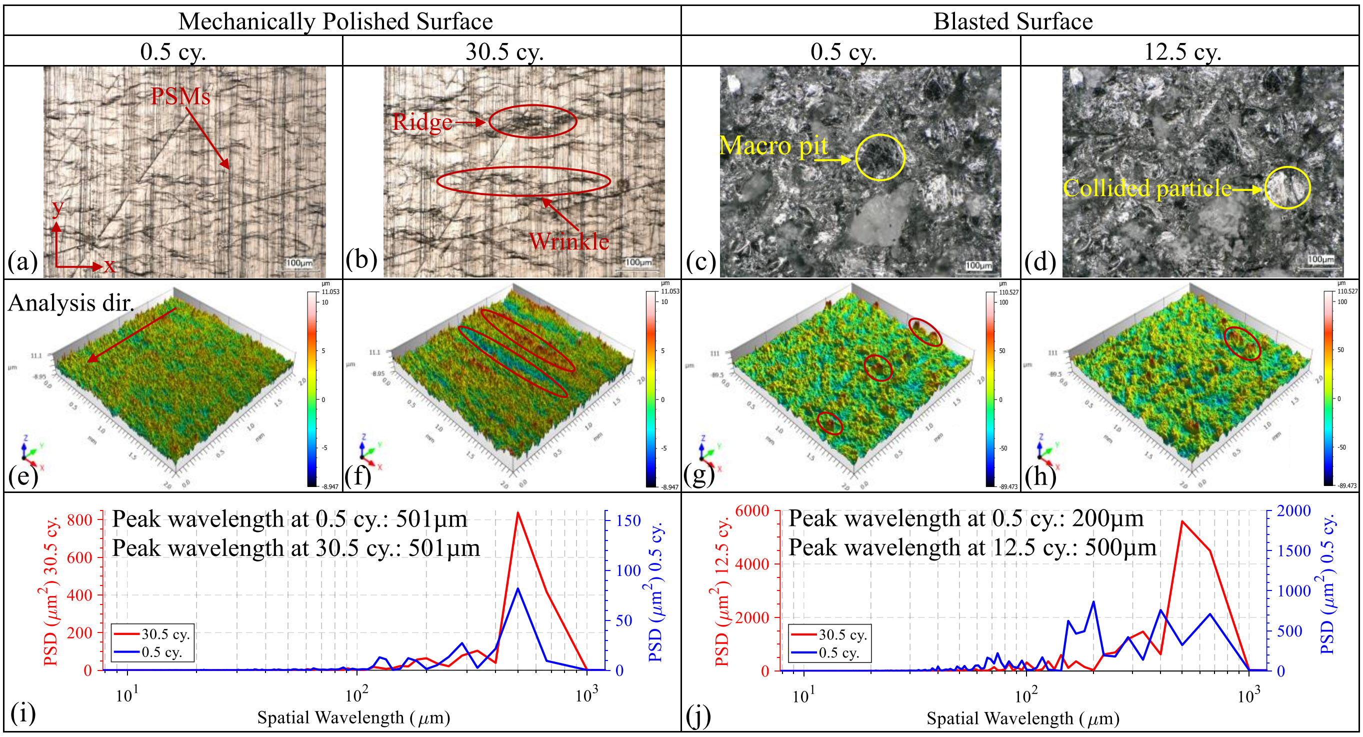

Fig. 4: Digital microscopic (×500), 3D topographic images and avg. PSD for mechanically polished & blasted surfaces

3.2. Effect of Roughness on Fatigue Life

Table 2: Surface characterization parameters for mechanically polished and blasted surfaces

Roughness Parameters	FM-40-5S		FB-49-5S	
	0.5 cy.	30.5 cy.	0.5 cy.	12.5 cy.
Sa (µm)	1.44	2.07	12.35	13.21
Sq (µm)	1.81	2.64	16.21	17.48
Sp (µm)	10.20	17.84	102.93	93.61
Sv (µm)	7.80	14.44	87.75	85.31
Sz (µm)	17.99	32.28	190.68	178.92

Surface modification methods are of paramount importance in affecting the surface quality. Moreover, roughness produced by modified methods affect fatigue properties more than steel grade. Table 2 shows the 3D surface characterization parameters including Sa (arithmetic mean height), Sq (root mean square height), Sp (maximum peak height), Sv (maximum valley depth), Sz (maximum profile height) for both specimens at start and end of loading. FB-49-5S shows higher average roughness (Sa) value of 13.21% than FM-4-5S with Sa value of 2.07%. Lesser value of Sa for polished surface is due to the removal of asperities after processing. According to facture mechanics, the higher the surface roughness value, the higher the notch effect will be i.e., more stress concentration leads to worse occurrence of fatigue phenomenon. Numerous microscopic notches appear on the metal surface after processing affecting fatigue life. Cracks nucleation rate appears to be higher for blasted surface at lower number of cycles.

4. SUMMARY

1. Higher strain is obtained for blasted surface and it is observed that surface texture affects the fatigue event more than grade of steel.
2. Power spectrum density analysis enabled to determine the change in surface geometry and functionality related properties of processed surfaces at the start and end of loading cycles.
3. Sa value for blasted surface is 6.37% higher than polished surface at the end of loading, and qualitative observations confirmed that machine polishing is more effective than surface blasting method in producing smooth surfaces.

REFERENCES

Natdanai, S., Eiichi, S. and Hiroshi, T.: Effect of High Strain Rate on Low-Cycle Fatigue Behavior of Structural Steel in Large Plastic Strain Region, Journal of JSCE, Vol. 4, pp.118-113, 2016.

