Author’s Accepted Manuscript

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PII: S0020-7403(16)30216-8
DOI: http://dx.doi.org/10.1016/j.ijmecsci.2016.09.010
Reference: MS3415

To appear in: *International Journal of Mechanical Sciences*

Received date: 27 April 2016
Revised date: 25 August 2016
Accepted date: 6 September 2016

Cite this article as: M. Abbaszadeh, J. Kadkhodapour, S. Schmauder and M Hoseinpour, A study on the effect of grain dimension on the deformation of sten struts in tension, bending and unbending loading modes, *International Journal c Mechanical Sciences,* http://dx.doi.org/10.1016/j.ijmecsci.2016.09.010

A study on the effect of grain dimension on the deformation of stent struts in tension, bending and unbending loading modes

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Abstract:

Coronary stents are medical/mechanical micro devices which are used to open the arteries occluded by the build-up over time of fat, cholesterol, or other substances. A wide range of studies should be conducted on coronary stents since they play an important role in the health of patients who suffer from heart diseases. However, due to micro scale of these tools, and also their gripping and loading complexity during a test, it is very difficult to conduct experimental studies to understand their behavior. Moreover, because of their micro dimensions and subsequently, existence of only a few grains along their thickness, J_2 flow theory is not appropriate to be implemented in order to define the mechanical behavior of such devices. Therefore, in this paper, 3D crystal plasticity finite element method (3D-CP-FEM) is used to understand the behavior of these devices. To achieve this goal and to find the hardening constants of strut, some simulations were designed and compared with an experimental study. Also, the effect of grain size in terms of w/d and l/d was investigated on the failure strain of struts under uniaxial tensile test. "w" and "l" are the width and length of the strut, respectively, and "d" is the average grain size. The results showed that failure strain increases within creasing w/d and decreasing l/d. Parameter waviness was used to measure the qualification of stent struts in bending and unbending simulations. Results revealed that the edges of strut are the critical areas and have more potential to failure. Additionally, it was found that with the increase in the w/d ratio, waviness decreases and the struts become homogeneous in behavior.

Key words: Coronary stents, Crystal plasticity, Finite element

1. Introduction:

Coronary arteries have the responsibility of the transmission of oxygen and nitrogen to the heart muscles. Blocking of these arteries is one of the most common and dangerous heart diseases which leads to heart attack and consequently, causes lots of people to die worldwide. Fatty deposits called atherosclerotic plaques build up in coronary artery wall and narrow the passage for moving blood through the artery. In some cases, when the blockage is not too extensive, the artery is reopened using angioplasty –inflating a balloon in the blocked area- but in most cases and when the occluded artery causes heart attack, surgeons use stents which are mounted on a balloon, deployed in the narrowed area, and inflated to permanently keep open the arteries.

Coronary stents are medical/mechanical micro devices which hold open the occluded arteries in a patient's lifetime. Micro devices are attributed to the tools where there are few grains in at least 1 direction [1]. Therefore, there are few grains in the deformation zone, the behavior of which affects the behavior of the whole device. For example, the failure strain of stent struts strongly depends on the hardening behavior of the grains along their thicknesses. This dependency is also strengthened with decreasing the number of grains in the desired direction. For instance, in struts with only one grain through their thickness, necking arises from the grain which is most suitably orientated for slip [2]. Overall, since there are few grains in such devices, any change in the size of a device and grain, and also in the number of grains and orientation will influence the mechanical response of a device.

In order for a better prediction of performance of stents during the stenting procedure and subsequently, to decrease the morbidity and mortality rates caused by stent failure within the artery, a wide range of studies is needed. However, due to micro structure of these devises, and also their gripping and loading complexity during a test, it is very difficult to conduct experimental studies to achieve this goal. Despite such difficulties, a few studies have been carried out in this area. Murphy et al. [3] showed that the stress-strain behavior of struts at micro scale changes with changing the size of specimen. They found that failure strain of the strut increases with increasing strut thickness. They also observed ductile fracture surfaces in struts with a large number of grains over the specimen thickness. Later, in another study [4], they focused on the effect of grain size on the ductility of stainless steel struts. Their results showed that ductility of struts increases with increasing the number of grains in the cross sectional area (CSA). By the use of 2D models, they also found a great improvement in ductility of struts when the ratio of CSA to grains exceeded 1000. Since experimental tests cannot encompass all possible cases - in terms of loading type, variety in stent dimension, and grain size - simulation plays an important role in understanding the behavior of stents under different loading conditions.

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