10th World Congress on Structural and Multidisciplinary Optimization
May 19 -24, 2013, Orlando, Florida, USA

Can we optimally design light-weight welded structures with sufficient fatigue resistance?

Norio Takeda[1] and Tomohiro Naruse[2]

[1] Hitachi Research Laboratory, Hitachi, Ltd., Ibaraki, Japan, norio.takeda.uf@hitachi.com
[2] Hitachi Research Laboratory, Hitachi, Ltd., Ibaraki, Japan, tomohiro.naruse.az@hitachi.com

Abstract

Mechanical designers have been required to develop light-weight products, such as transportation and construction machinery, because the light-weight products are suitable for a "sustainable society;" namely, one that must save raw material and fuel for operation of machinery. When welded structures in machinery are being designed, attention must be paid to their fatigue resistance, because they are subjected to cyclic loading during operation; hence, a welded part in such a structure could become an initiation site of a fatigue crack. The International Institute of Welding therefore publishes a recommendation that provides approaches for evaluating the fatigue life of welded joints. The recommendation gives three approaches, which are based on nominal stress, structural stress, and notch stress. When the welded joint to be designed is not simple enough to allow the nominal stress to be estimated, it is not easy to use the nominal-stress approach for fatigue assessment. In this case, the structural-stress or notch-stress approach can be used. As for these approaches, finite-element analysis is used to estimate stress at the welded joint. The structural-stress approach is particularly suitable for evaluating the fatigue resistance of large welded structures, because structural stress can be analyzed even with a finite-element model composed of shell elements; shell elements are frequently used to model a large structure.

In addition to the availability of fatigue assessment for large welded structures, the structural-stress approach, together with a structural optimization method, can be utilized to design a light-weight and reliable welded structure. As mentioned above, structural stress can be estimated with a finite-element model composed of shell elements. By means of shell elements, the thickness of a modeled structure can be handled easily as design variables during a process of structural optimization. That is possible because the shape of shell elements does not have to be changed to change only the thickness. However, even when only the thickness is optimized, a couple of issues remain to be addressed. For example, although two crack-initiation sites, i.e., weld toe and weld root, are possible in welded joints, fatigue failure of the weld root cannot be assessed by using the structural-stress approach; that is, the optimal thickness achieved by handling structural stress is not sufficient to avoid fatigue failure of weld roots.

In this study, a procedure for designing light-weight and reliable welded structures is proposed. The proposed procedure is composed of two processes: one is a structural optimization process, where the mass of a target structure is minimized by constraining structural stress, which has previously been proposed by one of authors; and the other one is the fatigue assessment process where the fatigue failure of weld roots is assessed on the basis of local-notch stress. To verify the effectiveness of the proposed procedure, an illustrative structure was optimally designed under structural-stress constraints. After this structural optimization, fatigue failure of weld roots at the welded joints having a root face was checked. Furthermore, the designed optimal structures were produced experimentally and fatigue-tested to verify that they have sufficient fatigue strength.