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Brittle and ductile failure constraints of stress-based topology optimization method for fluid–structure interactions

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ABSTRACT

This study considers failure theories for brittle and ductile materials in the stress-based topology optimization method (STOM) for steady state fluid–structure interactions (FSI). In some relevant studies, the subject of the stress-based topology optimization to minimize volumes with local von Mises stress constraints has been researched. However, the various failure theories for ductile and brittle materials, such as the maximum shear stress theory, the brittle and ductile Mohr–Coulomb theory, and the Drucker–Prager theory, have not been considered. For successful STOM for FSI, in addition to alleviating physics interpolation issues between structure and fluid and some numerical issues related to STOM, the mathematical characteristics of the various failure theories should be properly formulated and constrained. To resolve all the involved computational issues, the present study applies the monolithic analysis method, the *qp*-relaxation method, and the *p*-norm approach to the failure constraints. The present topology optimization method can create optimal layouts while minimizing volume constraining local failure constraints for ductile and brittle materials for steady state fluid and structural interaction system.

1. Introduction

The multiphysics simulation of fluid–structure interactions (FSI) is an important subject for a very wide variety of scientific and engineering applications. Computational complications in the involved physical theories have introduced novel ideas based on in-depth understanding toward physics and many numerical analysis procedures. Depending on differences in the manner of computational coupling between fluids and structures, these analysis procedures can be categorized as either staggered or monolithic analysis procedures (see [1,2] and references therein). Additionally, many studies can be found with regard to size and shape structural optimization methods for FSI systems, and there are some topology optimization studies for topological alternations or connectivity alternations inside FSI domains [2–9]. Furthermore, it is rare to consider brittle and ductile failure constraints in topology optimization for FSI [10–12]. To contribute to this topic, this study presents a new STOM method with the various failure constraints for FSI systems in corporation with the monolithic approach, *qp*-relaxation methods, and the *p*-norm approach.

Despite many topology optimization studies for a variety of engineering topics, few studies can be found for topology optimization for FSI systems. In [2], the theoretical difficulties with regard to applying existing analysis methods for FSI systems for topology optimization were discussed, and a monolithic approach was proposed for topology optimization. The study was extended to consider the mutual couplings among electric, fluid, thermal, and structures in [7]. Afterward, the monolithic procedure was extended to consider the local stress constraints for topology optimization in [13]. On the other hand, various numerical approaches have been proposed [5,7,14–17]. In [4,5], topology optimization for laminar and turbulent

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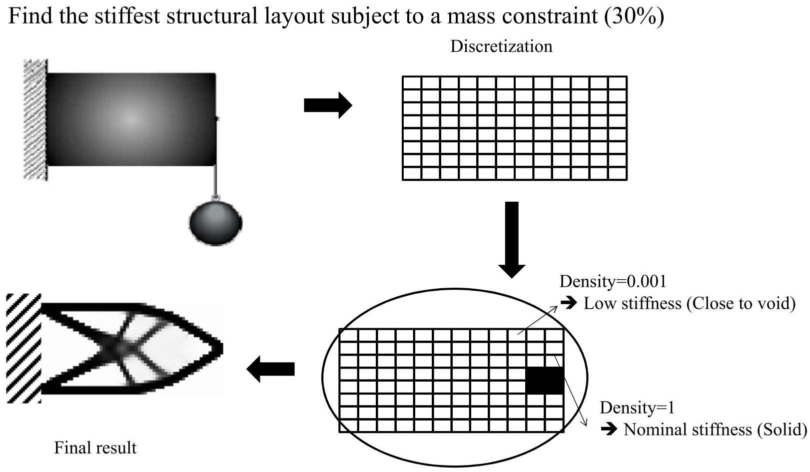

Fig. 1. Structural topology optimization practice.

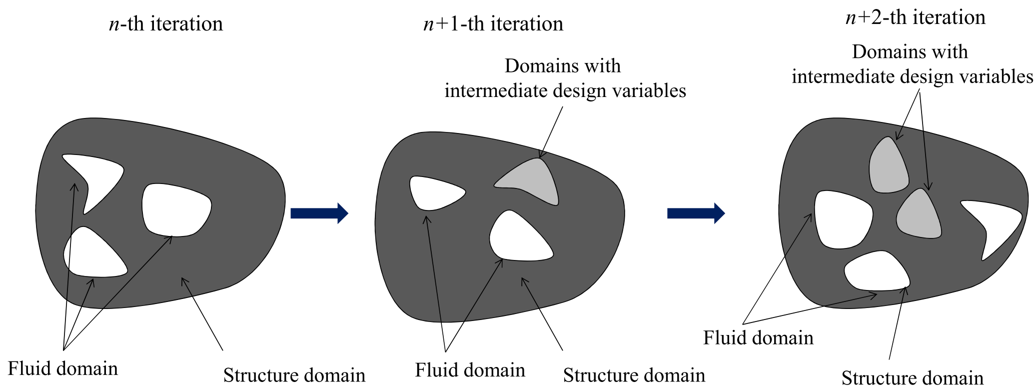

Fig. 2. Interpolating equations governing fluid and structure interactions.

flow including heat transfer was carried out. In [8], optimal shape designs were presented for a subsonic intake geometry using aerodynamic sensitivity analysis. In [15,16], some industrial optimization applications in electronic devices were presented. A saturated poroelastic actuator and FSI problem in the poroelasticity of shock absorbers were considered in [18,19]. Also, the reliability shape optimization methods were developed in [3]. In [20], the high-fidelity aero structure design method was proposed to reduce computational costs. In [14], a topology optimization method for the optimal flow channels in micro-mixers using the Boltzmann method while neglecting structural deformations was proposed. With standard FSI analysis methods, topology optimization was carried out for internal aircraft wing structures in [6] with high speed parallel algorithms. Turbulent effects were considered in [4,5,21] with the Spalart–Allmaras turbulent model. Furthermore, it was possible to discover many relevant studies for FSI, acoustic, and fluid problems in TO [6,19,22–27]. The shape optimization methods were developed in FSI in [3,20]. Furthermore, in an earlier study performed by our group [13], the von Mises stress constraints were considered in the STOM for FSI structures after resolving many theoretical and numerical issues [28–45]; in the present study, various failure theories for ductile and brittle materials are considered. Also there are some researches using the mixed formulation utilizing the displacement and the stress independently to improve the accuracy [42,45].

Issues of topology optimization (TO) for fluid–structure interactions

For a successful STOM for FSI system, several issues related to the multiphysics systems should be addressed [13]. Unlike purely structural topology optimization, some complicated and unclear points exist for topology optimization simulation procedures of the multiphysics system when optimizing the spatially varying density variables in Fig. 1. First, it is not clear how to interpret the two governing equations with regard to intermediate density design variables in Fig. 2. Due to this ambiguity, the state-of-the-art staggered or monolithic analysis methods for FSI systems developed to date have some difficulties to apply to STOM problems with ductile and brittle failure criteria. To overcome these difficulties, relevant researches have adopted monolithic analysis for FSI [2,7,46]. One of the most important differences between our monolithic analysis and the existing numerical analyses is that the linear structural equation and Navier–Stokes equation are governed at unified analysis and design domains. In our monolithic approach, the interaction–coupling boundary conditions are satisfied by modeling domain forces for the continuity of traction and clamp conditions for the continuity of fluidic velocity illustrated in Fig. 3. This monolithic analysis approach was applied toward structural optimization problems, including the