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Additive manufacturing technology with topology optimization for automobile parts

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We present a topology optimization of brake caliper for additive manufacturing, which is one of the most necessary automobile parts to reduce weight. The finite element analysis was performed to evaluate the mechanical properties on brake caliper parts. The topology optimization of brake caliper to which Ti-6Al-4V is applied has a higher safety ratio compared to the yield strength than the reference brake caliper. The precise shape of a brake caliper was manufactured using laser powder bed fusion (LPBF). Subsequently, heat treatment under the solution treatment condition decreased the yield strength due to increase machinability and ductility. The performance was evaluated by the JASO C406 test after post-processing and accessory assembly completed. The performance was similar to that of a commercial brake caliper, and it showed the possibility of using it as a product.

1. Introduction

The additive manufacturing (AM) process technology is rapidly being developed in recent years, and The Powder Bed Fusion (PBF) process is prominently used [1]. The PBF process which is mainly used in industrial applications is characterized by producing more sophisticated and complex [2]. The structural lightweight design for AM is always also an optimization task wherein dedicated topology optimization promises the highest potential in lightweight engineering [3]. The lightweight design and development process is specifically geared towards AM and an optimization concerning its weight wherein use is being made of the means and methods of nonlinear optimization, and specifically the dedicated topology optimization with the objective to reduce the weight of the structure[4]. The design of AM enables the methods of topology optimization to determine optimized lightweight structures that not only fulfill specified requirements but also can be manufactured in an optimal way[5].

Brakes of unsprung mass are most important safety parts in the vehicles and all of the vehicles have their own safety devices to stop their car. The increases in travelling distance as well as the growing weights of cars have made the improvements of lightweight part essential. An AM of effective topology optimization is needed to accomplish this performance of the brakes must be improved and important aspects of a caliper is low weight but at the same time high stiffness. Currently, brake calipers are produced with cast iron and aluminum materials by casting[6]. In case of complex structure, there are limitations in technical applications such as topology optimization for product weight reduction due to the casting process. However, since additive manufacturing is a process that builds layer by layer, complex products can be manufactured.

In this study, a new lightweight brake caliper model was designed and high strength properties are maintained using Ti-6Al-4V material. In addition, the topology optimization of brake caliper model was manufactured using the additive manufacturing process. Structural stiffness and brake performance characteristics were evaluated through structural analysis, and dynamo experiment.

2. Topology optimization of brake caliper

The brake caliper for lightweight was carried out using the topology optimization. The details of the topology optimization process are as follows. First, the design domain was constructed based on the reference design shown in Fig. 1(a). Oil-channels and assembling holes were set as a non-design area, and unnecessary areas for machining. The main bridge of the reference design was replaced by bolting, and two side bridge areas were added for finding a new load path. Fig. 1(b) shows the constructed design domain for topology optimization. The loading and boundary conditions were set for performance evaluation during topology optimization process. Hydraulic pressure was applied to the inner wall of the channel and the jig fixing regions of cylinder shapes were all fixed excluding the cylindrical rotation degree of freedom. The average deformation values of both outer surfaces extending the oil-cylinder centerlines were constrained for hydraulic pressure, and the average deformation values of the both oil-cylinder centers were constrained for braking force. As shown in fig1(c), the design model derived from the topology optimization. The topology optimized model was manufactured by the PBF process.

Fig. 1 Topology optimization of brake caliper and redesign process; (a) reference model; (b) Design model; (c) Topology optimized model.

3. Additive manufacturing

There are various manufacturing considerations in PBF process such as overhang angle and support design. The brake caliper is manufactured in the vertical. When the mechanical properties according to the angle are compared, the tensile strength of the horizontally produced specimen is high because the hydraulic system applies pressure in the direction of the piston. And then, to prevent support from being created because it cannot be removed when a support is created in the hydraulic channel inside the piston. The topology optimization of brake caliper was manufactured by PBF process based on the support design. Ti-6Al-4V is one of the difficult-to-cut materials. Due to the low thermal conductivity of Ti-6Al-4V, the heat generated during machining is concentrated only on the cutting edge of the tool. Crater wear weakens the cutting edge, leading to catastrophic tool breakage. Therefore, crater wear resistance is also an important characteristic required for tools when machining heat-resistant alloys. So, It is important to lower the mechanical properties of Ti-6Al-4V to reduce wear properties and improve processability. Solution treatment lowered tensile strength and increased ductility to improve product performance and processability. The topology-optimized part was manufactured by removing the support by CNC machining. In order to evaluate the performance of the topology optimized brake caliper, it was compared with the reference model. The test procedure of brake caliper was evaluated by JASO C406 test mode using brake dynamometer. The JASO C406 test procedure includes sequences of burnish, first effectiveness, first reburnish, first fade, recovery, second reburnish, second fade and recovery. Based on the result of JASO C406, the topology optimization of brake caliper shows similar performance to the reference model.

4. Conclusions

A new lightweight brake caliper model was designed using the phase optimization technique, and high strength properties are maintained using Ti-6Al-4V materials. The topology optimization technology is applied to manufacture high-strength and lightweight brake calipers. The topology optimization model of brake caliper was manufactured by additive manufacturing method. The brake performance of the topology optimized model was evaluated using the dynamo experiment. The new brake caliper was performed similarly to the reference model.

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