REVIEW ON DESIGN GUIDELINES FOR SELECTIVE LASER MELTING

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Abstract: *Selective laser melting (SLM) is a metal additive manufacturing (AM) process which is used for fabrication of complex geometry parts layer by layer directly from 3D CAD model. SLM gives boundless opportunities to build highly complex shapes which are not possible to achieve by traditional manufacturing process. however, SLM is not totally freeform fabrication as it has inherent process limitations. Design engineers frequently lack an understanding of these process limitations and their impact on the final part. Here comes the need for developing design guidelines for AM processes to help design engineers while designing the part for selective laser melting. This paper reviews general design guidelines that to be considered for building the part through SLM process. Research papers regarding support structure generation, part orientation and topologically optimization are referred. These rules aim to reduce cost, build failures, built time and wastage of material.*

Keywords: *Additive Manufacturing, Selective laser melting, Design guidelines*

1. INTRODUCTION

Additive manufacturing is an advanced manufacturing process which is used to build parts layer by layer directly from the CAD model. AM enables fabrication of complex geometry parts which are not possible by conventional manufacturing processes. Selective laser melting (SLM) is one of the prominent AM technique for producing complex geometry parts using metal powders [1]. Design for manufacturability (DfM) is adapted for easy manufacturing of designed products. DfM provide guidance to the design team in simplifying the product structure to reduce manufacturing and assembly costs and also to improve quality [2,3]. Additive manufacturing (AM) has brought design freedom to achieve complex geometric shape, material composition, and functional integration. The careful application of the design strategies can result in cost-effective, light-weight and high performance products. The design knowledge, processes, tools, rules, and methodologies all are different for DfAM than traditional DfM. Also, AM processes have different cost drivers than traditional processes and require different approaches to metrology and quality control. Therefore new guidelines are required to support DfM for additive manufacturing process, which can help designer to fully explore the potential of AM [3,4].

This review article will focus on overview of guidelines for part geometry, part orientation and support structure generation to reduce the uncertainties in the process like build failures due to overhang and warpage which will leads to increase in manufacturing cost. In addition to the DfM, a review of the concept of optimum design is also given, which is in demand for various applications. Reducing the weight of structures has become a priority for both economic and environmental reasons [5]. However, it is also crucial to maintain mechanical resistance in order to ensure the safety and lifecycle of product. Topological optimization helps to meet these requirements, making it possible to create innovative shapes. Topology optimized designs are not considered fully in conventional manufacturing process because all the complex geometries cannot be manufactured due to manufacturing constraints, whereas AM has potential to manufacture complex optimized parts [6].

2. DESIGN FOR ADDITIVE MANUFACTURING

2.1. Build Orientation

The orientation of the part is a very important factor considered during the built process. The Z-axis pointing vertically from the build plate is considered as built direction. In selective laser melting, using coating mechanism thin

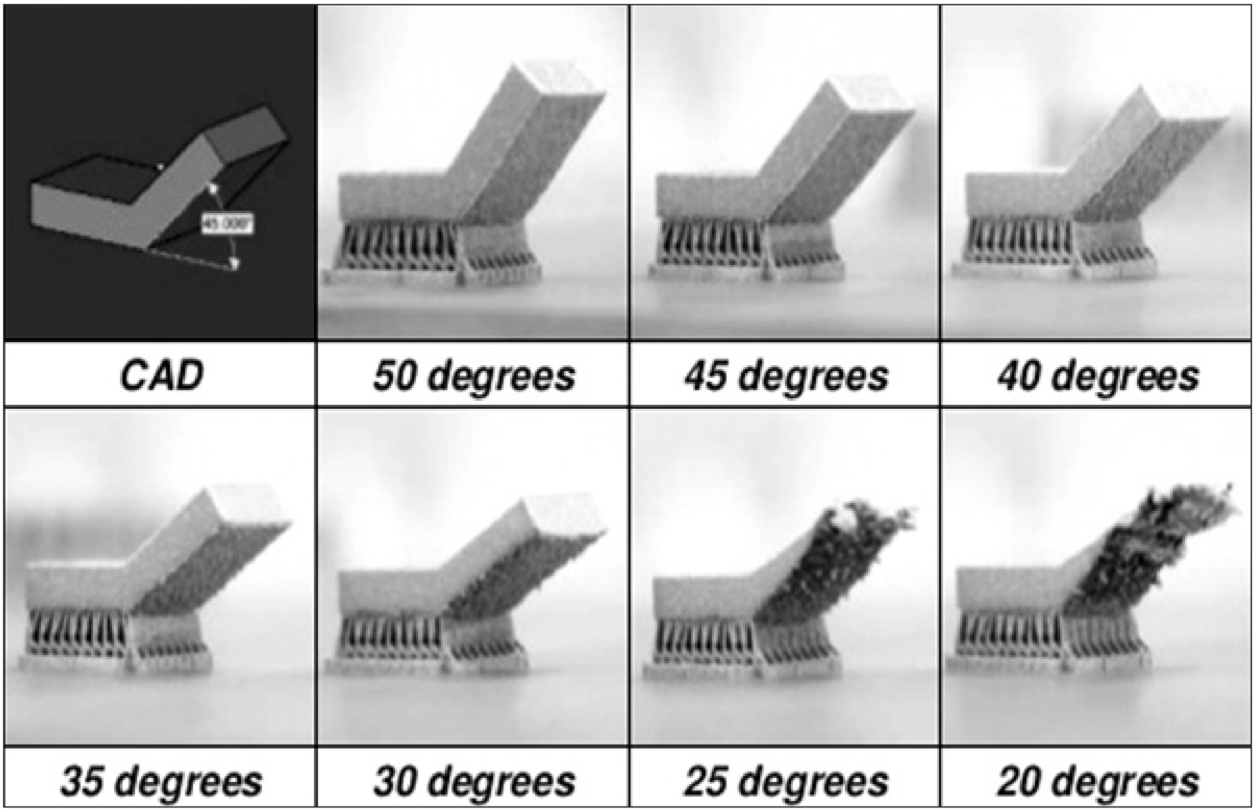


Fig 1. Parts Printedwith Different Overhanging Angles (Source: Solidworks)

layers of metal powder are evenly distributed onto a substrate plate. The substrate plate is fastened to an indexing table that moves in the vertical (Z) axis. First, layer has been distributed; each 2D slice of the part geometry is fused by selectively melting the powder. This melting is accomplished by using a high-power laser beam, usually an ytterbium fibre laser. Support structures are required for overhanging surfaces (at less than 45^o from the build platform), because the powder in the build chamber does not provide any support to the part as it builds as shown in fig 1. This supporting structure will then need to be removed by machining or wire cutting. Over hanging surfaces also known as down-skins possess rougher surface finish than vertical walls and upward facing surfaces due to the partial sintering of powder below the overhang. Overhanging surfaces more than 45^o does not requires support, as the previous layers provide support to the layer that is being printed. Hence, it is recommended to orient the part such that the angled surfaces will be more than 45^o to build plate[6-9].

During the selection of build direction, it should be feasible to remove the supports and the powder after the build is completed. Fig. 2 shows, the cage part built in level orientation and at 45^{o}orientation.

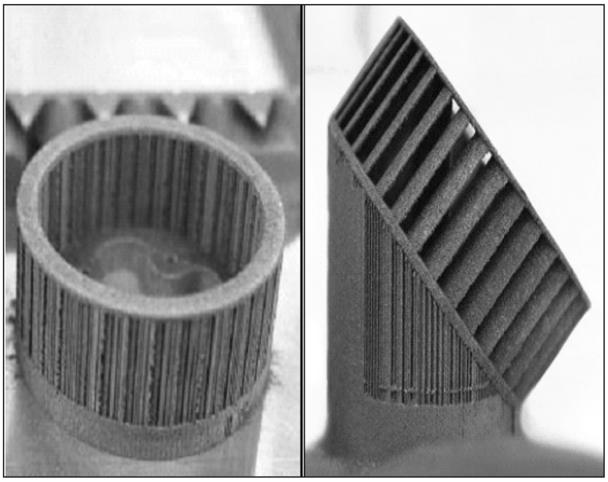
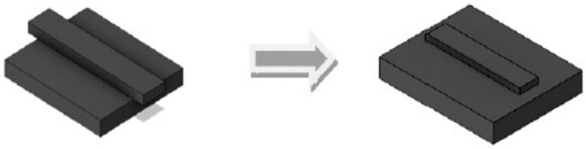
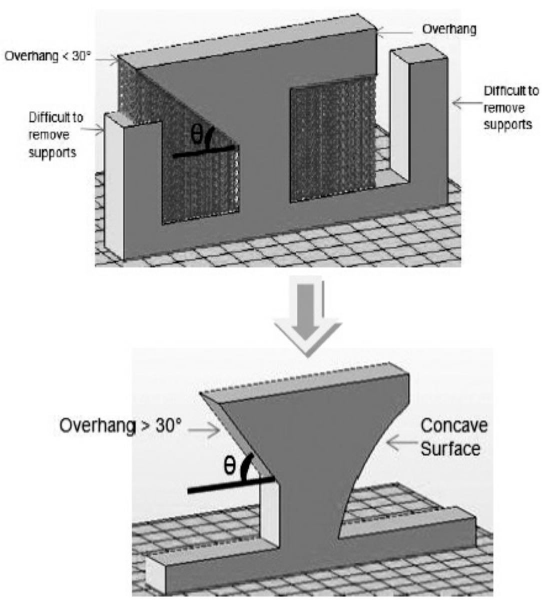
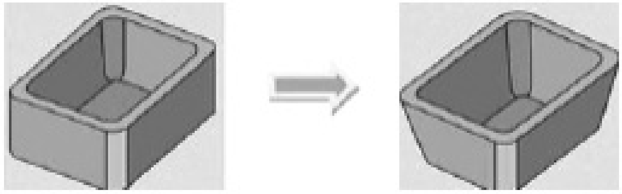
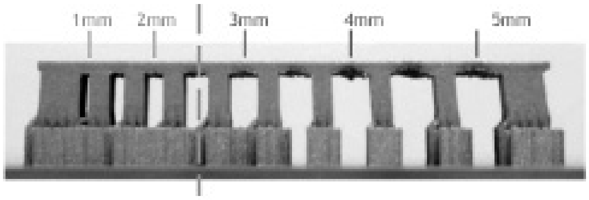
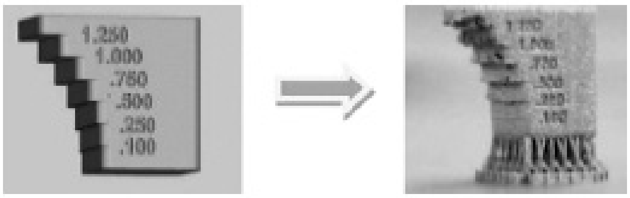
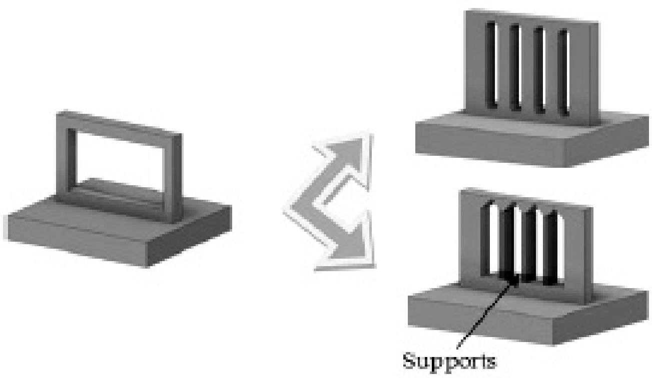
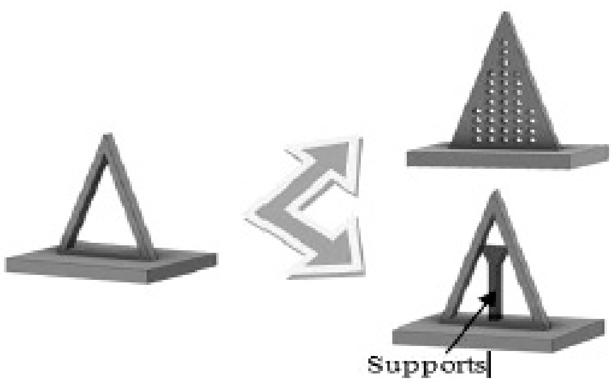


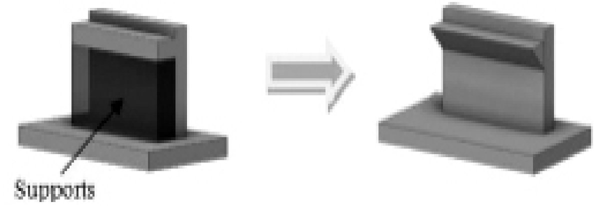
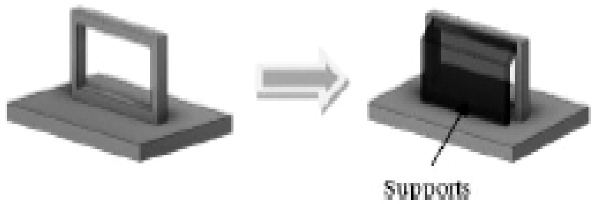
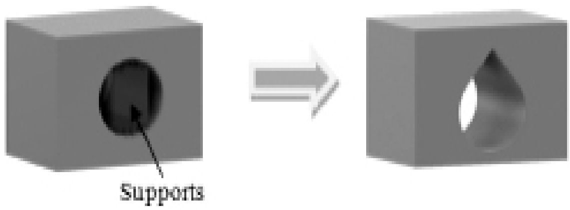
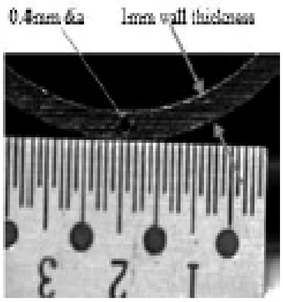
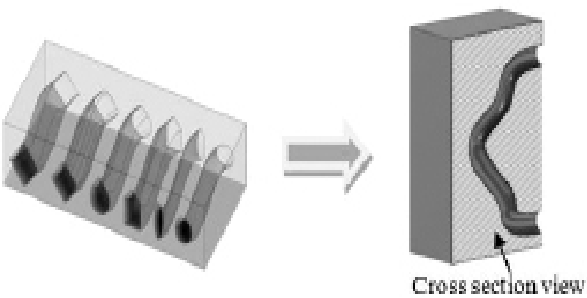
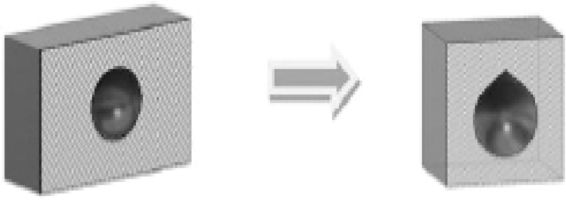
Fig 2. Cage Orientation at 0° and 45°
(Source: Additive Manufacturing of Metals, Springer)

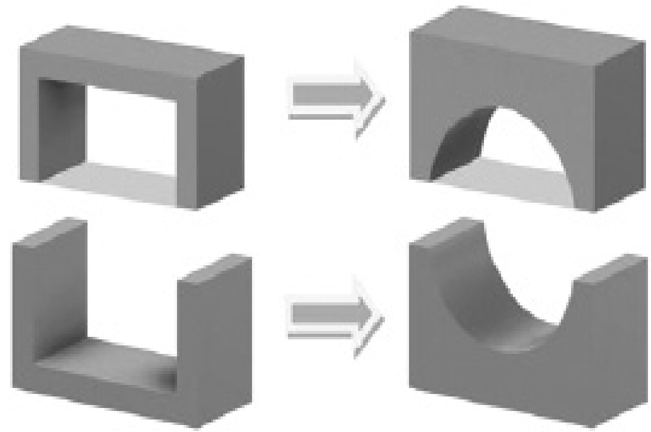
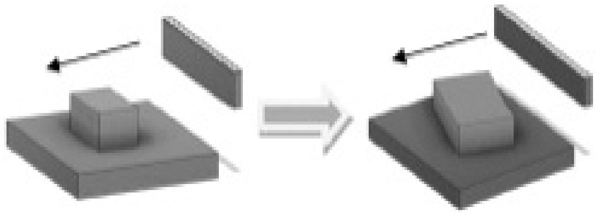
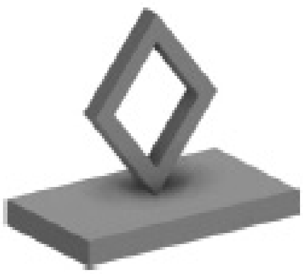
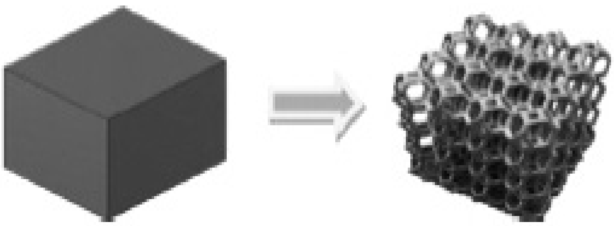
If the cage part is built in a level orientation, supports are needed between the fins to hold the form as it grows. It is not feasible to remove the supports as it is inaccessible. But when the part is oriented at a 45°, those supports between fins are not needed [10]. And also, Z height should be minimum to reduce the build time [4,8].

2.2 Design Guidelines

Design Guidelines		
No.	Geometry	Remark
1		The part size should be in built volume of machine. If require, change the orientation or split the parts [7,11].
2		The fillet (R=3 to 5mm) between the interface of the part and substrate prevents distortion during printing [11].
3		The laser diameter limits the manufacturing of sharp corners and edges. It is better to design parts with radius of 0.5 mm [6,7,11].
4		Provide the radius to bottom surface for avoiding the supports [11].
5		Prefer to design the overhang with recommended length or provide the self-supporting concave or convex geometry or avoid the surface inclination below 30°-45° to prevent support structure.(Self supporting angles for stainless steel - 30°, inconel - 45°, titanium - 20° to 30°, aluminum - 45°, cobalt chromium- 30°) Provide the easy support removal geometry to the part for final machining [4,7,11,13]

6		Provide the draft angle 0.5° to 1° for easy removal of part from mould [17].
7		Aspect ratio should be not be more than 8:1 or provide a bridge in-between two sections. It avoids the deformation over the increase in the length [8,16].
8		Minimum self-supporting bridge distance is 2mm [10]. Bridge gap more than 2 mm requires support.
9		If the next layer is larger than the previous layer, it will create the overhang and allowance for self-supporting overhang is 0.5mm [10].
10		Provide semicircular slot for self-supporting, if only cooling or weight reduction is required. If cooling and weight reduction is not required, provide series of self-supported angles [8].
11		During building process the triangular section will be very weak at the apex. Provide rigidity by applying simples support structure or add holes (dia. less than 6mm) [7].

12		If design permits, provide the chamfer of 45^{o} to the overhang to avoid supports [7].
13		Provide the offset support for overhang surface for easy removal by wire cutting [7].
14		Hole diameter ≥ 8mm requires supports. Use tear drop shape to avoid support generation [6,7,9,11,13].
15		Minimum wall section should be ≥1mm and horizontal/vertical hole diameter should be ≥0.4mmfor most of the materials[7]. Finer structures are possible, but are dependent on material, orientation, and printer parameters.
16		It is very difficult to remove the supports from the irregular channels. Hence, it is recommended to use hole diameters less than 8mm or use tear drop, ellipse, pentagon section to avoid the supports [6,13,15].
17		Internal cavities should be printed with tear drop shape with top angle ≥45^{o}, since sphere shape requires support, which is not feasible to remove. During the build, a gate can be given or a hole can be drilled after the build is completed to remove the powder and it can be plugged [7,13].

18		Avoid down facing. Support structure can be reduced by placing and orienting the part adequately [11,14].
19		Avoid deformation by aligning the part in inclination of 5° with recoater. Inclined surfaces should be oriented opposite to recoater movement[7].
20		Provide 45 degree orientation for self-supporting the part. This will reduce the post processing time and material [7].
21		Use lattice structure or cavities to reduce the part weight. It also reduces built time and cost. [6,12].

2.3 Support Structure

In metal additive manufacturing, support structures support the overhanging features are laid over support structures. Support generation also minimizes deformation, dissipates heat from part to the substrate and prevents build crashes [17].

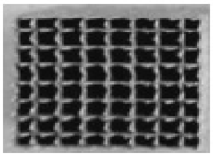
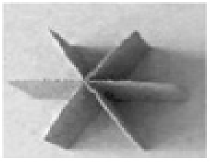
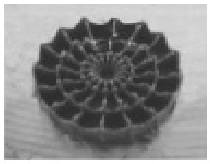
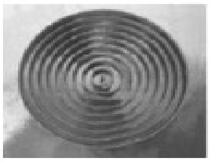
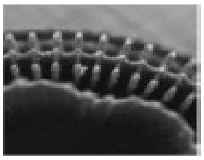
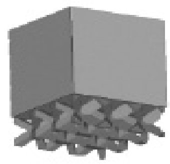
The removal of support structures is done manually in the case of the metal process. Post-processing for support structures requires time to be cut or milled off after printing which leads to increase in the labour cost and manufacturing time. The different support methods will give different surface roughness [19].

Table. 1 show different types of supports, each with its unique benefits. Selecting proper type of support according to application requirement will lead to the best results [18,19].

2.4 Topology Optimization

Topology optimization is a process of finding the optimal distribution of material and voids in a given design space, dependent on loading and boundary conditions, such that the resulting

Table 1. Different types of support with applications

No.	Type	Geometry	Applicable
1	Block		Volumetric massive part
2	Point		Small features
3	Web		Circular geometry
4	Contour		Contour of parts
5	Line		Narrow down facing area
6	Lattice		Between part downskin to build plate

structure meets prescribed performance targets. Topology optimisation software helps to find best design with minimum weight for a given loads, by specifying where the supports and loads are located on a surface of design volume. Although topology optimization has been an available design tool for a few decades, traditional manufacturing processes restricted and concealed its full potential. This consequence is changing now with the continuous development and increased use of AM in industry. With AM, it is possible to print almost any solid geometry by applying few DfAM rules[13,20].

Lattice structure can be used to reduce the weight and increase the surface area. In biomedical applications, lattice structure provide adequate surface area and porosity for cell growth. The lattice structures can be generated in topology optimisation softwares[21].

2.4.1 Case Study

An ECU (Engine Control Unit) is an electronically controlled fuel injector that accurately supplies the fuel required by the engine using a computer based system. It contributes to reduce the harmful element in exhaust gas by controlling the amount and timing of fuel injection. An ECU unit is mounted on diesel engine by using frame as shown in fig. 3(a). After topology optimization as shown in fig. 3(b)there is a 12% reduction in weight with same heat dissipation performance as compared to traditional design. Due to increased surface area, heat dissipation efficiency is improved [22].

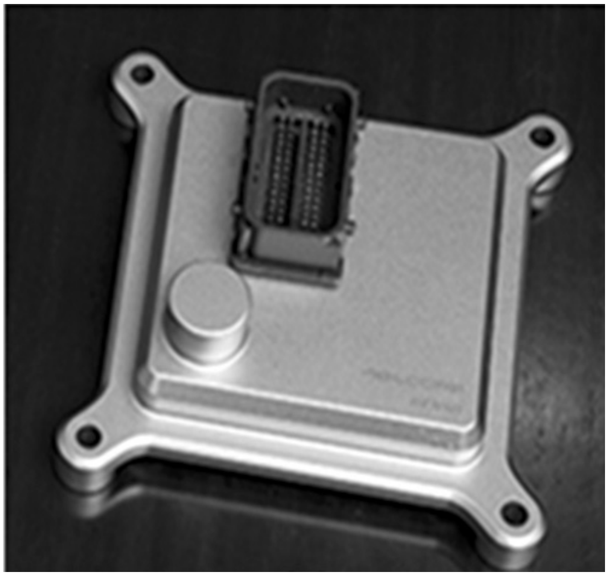


Fig. 3a

Fig. 3b

Fig 3. Autodesk Redshift Denso-ECU Case Study (a) Traditional Diesel Engine ECU Frame (b) Initial Topologically Optimised Part (c) Final Part (Source: Autodesk Redshift Denso ECU)

3. CONCLUSION

Design guidelines to help design engineers while designing the part for selective laser melting process are reviewed in this article. Major factors to be considered while designing for SLM are the build orientation, support generation, topology optimisation and process limitations. Some minor geometrical modifications can reduce post processing time and cost of manufacturing to a greater extent. Self-supporting angle is different for different material composition. An optimized part orientation and support generation plays important role in reducing built time and surface quality. Though AM provide design flexibility it has feature size restrictions like minimum wall thickness, minimum fillet radius, layer thickness, aspect ratio etc. Topology optimisation and lattice structure approach significantly reduce mass with improvement in mechanical properties.

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