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Materials opportunities in layered manufacturing technology

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Layered manufacturing technology describes a range of techniques where 3-dimensional objects are constructed from a laminated form. There are a range of methods by which this can be achieved but all rely on the same fundamental set of processes. First the object to be fabricated must be described in terms of an accurate 3-dimensional design representation. This must then be reformatted to describe the object in terms of a number of slices with finite thickness. This "slice information" is then used to fabricate the appropriate number of slices from the desired material. Finally these slices are assembled to form the solid object. In practice a number of the current technologies combine the slice fabrication and assembly processes by using a previously deposited slice as the template for the deposition of subsequent slices.

In practice the techniques manufacture an approximation of the desired shape by building the object from a number of discrete building units of fixed size. This simplified form can then be built in the absence of tools, moulds or dies. Thus, the technologies represent a trade-off between ease of manufacture without tools and accuracy of the final surface representation. The manufacturing method of laminated object building may also limit the fabrication speed as this will be limited by the rate at which the fundamental manufacturing blocks can be deposited.

Clearly, there is a direct analogy between layered manufacturing and a number of traditional manufacturing methods.

- The fabrication of objects from fundamental building blocks exactly mirrors the construction of buildings using masonry bricks.
- The representation of 3-dimensional landscapes using slices defining contour intervals has been used for many years in cartography.
- Traditional manufacture of pottery has used the sequential layering of a thread of clay to fabricate thin walled objects.

Modern practice has taken this concept to develop layered manufacturing technology, but the size of the building blocks has now shrunk considerably with the fabrication unit now being typically in the range 10–100 μm.

The current interest in layered manufacturing has its roots in the technology of *Rapid Prototyping*. Rapid prototyping developed to fill a need in manufacturing industry to develop representative or functional prototypes of objects normally manufactured in large quantities by tooled processes. Rapid Prototyping is a method of producing a pattern very rapidly, which can then be used to manufacture a small number of objects to test function before incurring the major expense of production tooling.

There are now a relatively large number of rapid prototyping techniques available commercially. These technologies are relatively mature and play an important role in a number of industries. Because of their historical development as pattern making and visualisation tools, the range of materials available is relatively limited with the majority of parts fabricated from, polymers, waxes or paper/textiles. At present it is possible to build accurate objects with tolerances in the region of 100 μm out of epoxy resins or acrylates by *stereolithography*, engineering thermoplastics by *selective laser sintering* or *fused deposition modelling*, cellulose paper by *laminated object manufacture*, and wax or thermoplastic by *ink-jet printing*. The notable exception to this list is 3D printing, initially developed at MIT to directly produce ceramic parts. For a detailed review of these technologies the reader is referred to reference [1].

In order to use these methods to directly manufacture components, the range of available materials must be extended to a wider choice of engineering materials, particularly including engineering alloys, engineering polymers and technical ceramics. To date, the materials used in these technologies have been chiefly chosen to optimise the manufacturing process and produce clean, well defined objects. Although there are large markets for parts in engineering thermoplastics, for layered manufacturing to become an important manufacturing technology the range of materials from which parts can be made will need to be substantially extended.

A major market is the field of rapid tooling where the ability to manufacture materials processing tools directly from computer files would lead to significant cost savings and reduced time to market. To achieve this we need the ability to directly manufacture parts out of tool steels and other wear resisting materials.

Laminated manufacturing processes have other potential applications in industries where short production runs are normal and tooling costs are a significant part of the manufacturing costs. One such market is that of technical or engineering ceramics where parts are often complex but produced in relatively small quantities. There are other application areas where features of laminated object manufacture can be exploited. It

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is a common feature of most of these manufacturing methods that re-entrant or hollow shapes can be fabricated. This allows the manufacture of materials with controlled porosity and the direct fabrication of micromechanical devices. Porous materials are of great importance for bio-medical applications. Organic bone materials are complex hydroxyapatite (calcium phosphate) collagen composites with an interconnected internal porosity of length scale 100–300 μm. Currently it is thought that successful prosthetic implants should contain sch a scale of porosity to promote biocompatibility and bone intergrowth. Laminated manufacturing technologies may provide the best route to fabricate such structures.

Current laminated object manufacturing technologies can be, and have been, adapted for the direct manufacture of ceramic and metal parts for some time [2, 3]. The majority of this work has used commercial machines and adapted them for use with new materials. Although these attempts have been successful and there are commercial products manufactured, for laminated manufacturing technologies to become a useful manufacturing tool substantial development needs to be achieved, particularly in the area of new materials development.

The following collection of papers were presented at the Second Workshop on Materials Opportunities in Layered Manufacturing Technology, held in Manchester in June 2001. The objectives of the meeting were to review the current state of new materials developments for these manufacturing technologies. A number of applications are presented including: direct manufacture of injection moulding tools, engineering ceramics, functional ceramics and biomaterials.

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