High Velocity Compaction : Overview of Materials, Applications and Potential

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Abstract

Through different projects, CETIM and its scientific and industrial partners have evaluated the potential of the High Velocityy Compaction Technology in terms of materials and component shape. Various kinds of powder materials were studied: metals, ceramics and polymers. The HVC process was used with success to manufacture gears, large parts and multilevel components. Due to the high density of HVC parts, the green machining process enables shapes to be produced that would otherwise be impossible to compact and components to be produced with very hard sintered and homogeneous materials.

Keywords : High Velocity compaction. Metals, Ceramics, Polymers

1. Introduction

High velocity compaction is an emerging technology that has started to be used in industry. In 2000, CETIM anticipated this development and purchased a machine able to manage the development work required for use in this process. Our high velocity press can reach velocities of 11 $m.s^{-1}$, producing up to 20 kJ of energy. In addition, with up to 5 shots/s, it can offer a new "multi-shot" functionality, which can be very useful for producing large parts (3 kg) on a fairly small machine. Additional equipment includes automated peripherals and a batch furnace with a capacity of up to 1600°C, for validating part feasibility and manufacturing the pilot runs required for process qualification.

In conjunction with its industrial and scientific partners, CETIM used different applications to assess the potential of HVC (large scale parts, gears, multilevel parts) with various material grades (steels, ceramics, polymers).

This article provides scientific results and example applications to give a summary of the potential of high velocity compaction.

2. High velocity compaction

Powder compaction by impact is very similar to uniaxial die-pressing. It differs from the conventional process mainly by the way the compaction force is applied. Conventional die compaction (CDC) applies a load slowly using a mechanical system or hydraulic pressure. Either the load or the pressing travel is controlled and pressing time is approximately 1 second. The press slide has negligible kinetic energy in comparison to the mechanical energy transferred by the force applied. With dynamic compaction, on the other hand, the pressing force comes from kinetic energy spreading from a mass moving at high velocity (11 $m.s^{-1}$). The load is applied for a very short time, less than 0.01 second. In this case, the acceleration force applied to the slide is negligible in comparison with the force applied by the high-energy impact. This is a high energy density process, producing an extremely intense compaction. The energy spreads via the elastic-plastic deformation of the powder, friction between particles and between the powder and tooling, via elastic deformation of the tooling and by heat generation. An intense amount of heat may be produced by the compaction, leading to material softening. As the compaction lasts for a very short period, there is limited heat exchange, and this is referred to as an "adiabatic" phenomenon, which leads to a modification in the behaviour of the powder mixture (base material + alloy elements + lubricants) on compaction.

3. HVC forming of various materials

CETIM has carried out various projects to assess the effect of HVC on various materials: metals (Fe, structural steel, tool steel, W-Cu, Cr-Cu alloys), carbides (WC, SiC), ceramics (alumina, MgF_2) and polymers.

Metals. A study [1,2] on compaction and sintering behaviour of Fe-based powders showed that springback is reduced with impact compaction (0.18 %) as compared with the conventional process (0.28 %). Part ejection is therefore easier, suggesting tooling wear could be reduced. In addition, mechanical stress on the die is 10-20 % lower with HVC than with CDC. Up to three times less significant shape defects are found in HVC green compacts and anisotropic shrinkage is slightly less marked when sintering HVC parts.

Ceramics. When forming Alumina powders with the HVC process [3], up to double the forming pressure can be used (to 1200 MPa). With conventional pressing, these levels cause problems at compact ejection. The density of green parts is therefore +8-9% higher than those produced with a 400 MPa conventional compaction. With HVC, the compact pore size is smaller, meaning the sintering temperature can be reduced to achieve a smaller grain size, leading to improved properties. After sintering under the same conditions (1500 °C, 1 hr), HVC parts are slightly denser, with density values up to 99 $\%d_{th}$.

Polymers. HVC proves to be a particularly innovative technology for forming semi-crystalline polymer. A joint study [4] is currently underway with INSA Lyon (France) into high velocity compaction of High-Molecular Weight PolyEthylene. Cylindrical parts have been manufactured at temperatures approximately 25 °C lower than the polymer's melting point, using several impacts of up to 100kJ. The mechanical properties of the parts are very interesting, with a Young's modulus 1.5 to 2 times greater than that of sintered parts and a tensile stress properties and a yield point equivalent to those of a sintered part. Intergranular welding mechanisms are still not fully understood but it would appear that the "sintering" undergone by these parts occurs via melting/recristallisation phenomena at the grain surface.

4. Industrial parts

Through various feasibility studies, CETIM showed that parts with internal gearing (splines) or external gearing over the full height of the part or just a particular section could be manufactured using this process (Fig. 1). In all cases, very high density in the order of 7.5 $g.cm^{-3}$, was achieved. Extremely large parts that can be impossible to manufacture on conventional presses (ex: 180 mm discs or 2 kg tubes) can also be processed on fairly small machines. HVC can be used to produce complex, tapered shapes and multilevel parts in a single stage, with homogeneous density across the whole part. Moreover, high-density parts produced by HVC are particularly suitable for pre-sintering machining operations, whatever the material (metals, ceramics…). This "green machining" can produce shapes that cannot be made using compression, such as grooves, thin webs and internal threads (Fig. 2). Green machining can also be used to make parts with difficult materials such as tool steel and some Cobalt or Nickel-based alloys, or even using un-machinable materials such as tungsten carbides or ceramics.

a) b) c)

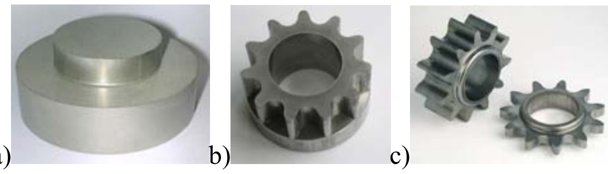

Fig. 1. Multilevel part (a) and parts with gear teeth

a) b) c)

Fig. 2. HCV parts finished by high-velocity green machining a) alumina b,c) steel

5. Discussion

This overview shows that high velocity compaction offers significant advantages when applied to various materials. Increased density after compaction should lead to less energy-intense consolidation heat cycles and lower shrinkage, reducing the risk of deformation and scrapping. Compacted parts made with certain materials have increased cohesion characteristics, meaning "green machining" is possible. Better control of shrinkage characteristics should mean parts are produced closer to the desired dimensions.

Another notable advantage of the high-velocity process is that users with little prior experience can compact industrial powders to high densities. Not only is it an alternative, but a complementary technology to work alongside current processes. It will be used in producing large, high performance parts, and a broad range of materials from polymers to ceramics and metals.

6. References

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