On the benefits of using a STRECON die for the compaction of powder metals.

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ABSTRACT

The intention of this study is to explore the impact radial stress has on the creation of microcracks for metal compacts during ejection. Two modes of ejection were investigated, regular ejection and STRECON ejection, a method designed to first reduce the radial stress on the cylindrical compact before ejecting. It is the presence of radial stress that is believed to influence the creation of microcracks, thus reducing this stress should reduce the amount of cracks [1]. Ejection in the regular sense is done by removing one punch and running the other punch through the die until the compact falls out. The use of a STRECON die, specially designed with an inner insert, allows radial stresses to be reduced before ejection. When this insert is moved axially it slides on a conical surface and results in a slight increase of the inner die diameter. The data sets consist of tablets pressed to relative densities of 70%, 80%, and 85%. The effect of radial stress on surface defects is characterized by the use of scanning electron microscope images and by diametrical compression testing used to compare the strengths of the compacts. This study shows that there is definitely an effect on surface conditions of the copper compacts, though the full impact is not yet completely understood.

INTRODUCTION

Subjecting loose particles to high stress will create a compact matrix that carries a unique set of properties. Tablet compaction through the use of cylindrical dies and simulations has been widely studied [2-3]. One of the major influences on tablet properties is the compaction pressure because of the effect pressure has on density. Generally the denser the compact, the greater the outward forces, and the higher the die wall friction is [4]. This was seen in a parallel experiment where it
took approximately 50 MPa to eject a sodium chloride tablet with a relative density of 90% and 85 MPa to eject a sodium chloride tablet with a relative density of 96%, using the same die set up.

The scope of this experiment is to help characterize the effect of reducing radial stress on the ultimate strength of a compact. If microcracks are eliminated than the likelihood of fast fracture is reduced since propagation could be initiated from a microcrack \textsuperscript{[5]}. A reduction in the amount of microcracks would increase the durability of the compact and reduce the amount of cracks seen on the surface of a product. This information is useful to any industry that is based on the formation of a product through die compaction like precision metal parts, pharmaceutical tablets, and ceramic products.

EXPERIMENTS

Instrumentation

The compacts were made using a specially machined cylindrical STRECON die shown in Figure 1 below.

![Figure 1. Punch and die configuration for creating the compacts (1) outer die, (2) inner die, (3) bottom punch, (4) top punch, (5) copper powder](image)
The die is made up of two pieces, an inner and outer die. When the conical inner die is ejected it expands which widens the chamber around the compact. It is this expansion that is responsible for the reduction of radial stresses, which lowers the ejection pressure needed to force the compact out of the die. The diameter of the compaction chamber in the inner die is 0.5 inches, or 12.7 mm. The load was applied to the punches by a hydraulic press (Baldwin) housing a 50,000 kg load cell outputting with a resolution of 100 N. The press is operated manually by opening and closing hydraulic valves, which does not allow for an easily measured strain rate. Once the valve is open and loading begins, the pressure rises and will rise at an exponential rate as the compact becomes more and more dense. The valve is slowly closed until the desired load is reached. After compaction is complete, the same press is used to eject the copper samples from the die.

Before breaking the compacts they were measured with a 0.0001g resolution scale (Sartorius) and a 0.001 mm resolution micrometer (Mitutoyo). Diametrical strength testing was conducted using an Engineering Systems CT5 producing analog signals that are then interpreted by a MATLAB program. The CT5 has a 500 kg load cell with a resolution of 0.01 N and the speed used to test the tablet was set to 1.7 mm/min for this study. Figure 2 below shows the loading mode of diametrical compression and the effect it has on these copper compacts.

![Figure 2. Loading mode of diametrical compression and its effect on a copper tablet](image)

The scanning electron microscope (Zeiss) images were captured at both 5 kV and 10 kV. These images were taken of the outer surface of the tablet after the diametrical compression tests were completed. The images were not taken from the plastically deformed section of the tablet in contact with the CT5 platens. Images were taken at 100x, 250x, 500x, 1000x, and 1500x.

**Materials**
The material used for the compacts is 99.3% copper (ChemicalStore.com) formed from water atomization. The copper has a mesh of 150 and an apparent density of 2.7 g/cc. Tungsten disulfide, a solid lubricant, was used between the inner and outer die to allow for easier removal. The tungsten disulfide (Lower Friction) is pure 99.9% with a particle size of 0.6 microns. The lubricant did not come in direct contact with the copper used for the tablet and therefore does not directly affect the ejection of the compact.

**Methods**

The tablets were compacted at three different pressures to achieve three different relative densities. The pressures used were approximately 197, 395, and 513 MPa resulting in relative densities of 70%, 80%, and 85% respectively. They have a cylindrical geometry with an aspect ratio (height to diameter) of approximately 0.35. The compacts were made in the exact same way up until the ejection step. To reach the proper aspect ratio, approximately 3.5 grams of copper was used for the 70% relative density tablets while 4 and 4.2 grams correspond to the 80% and 85% relative density tablets. The two ejection modes explored are shown below in Figure 3. In the regular ejection mode the compact is pushed all the way through the die after the removal of the bottom punch. STRECON ejection is shown on the right of Figure 3. The figure illustrates how the radial stress is relieved by the ejection of the inner die. As the inner die is pushed down it is allowed to expand, relieving some of the stress on the tablet.

![Figure 3](https://via.placeholder.com/150)

*Figure 3. The left shows ejection in the normal sense and the right shows STRECON ejection reducing radial stress. (1) outer die, (2) inner die, (3) upper punch, (4) compact.*
The compression tests were conducted until the point of failure, which is defined as when the tablet reaches its peak stress, shown below in Figure 4. Diametrical compression subjects the middle of the tablet to tension in the outward direction (left and right, consult Figure 2). The tablet is placed on edge and compressed by two rigid platens on the CT5 at a constant test speed of 1.7 mm/min.

![Diametrical Compression Stress vs Displacement](image)

**Figure 4. Example of stress curve obtained from the MATLAB data and definition of diametrical compression failure.**

A scanning electron microscope was used to take pictures of the tablet surface in contact with the die walls. There was no need to coat the compacts with a conductive film since copper itself is conductive.

**RESULTS AND DISCUSSION**

The STRECON ejection method did considerably reduce the ejection pressure needed to remove the tablet from the die. The pressure needed during regular ejection was not recorded, but is noted as significant. The ejection pressure of the tablet during the STRECON ejection was practically zero. After the ejection of the inner die, the copper tablet would fall out of the die without any external influence needed. This confirms that the design theory for the STRECON die holds true, it does in fact reduce the pressure needed for ejection by the release of radial forces from the die.
This effect depends on the axial expansion from die size of the material compacted. If the change in die diameter is larger than the expansion from the compact essentially there is no radial stress left. Otherwise the radial stress is simply reduced but remains non-zero and thus a smaller but non-zero ejection force is required.

The mechanical testing performed shows little to no difference in strength across the three relative densities. This is an expected result since cracks introduced from ejection should exist perpendicular to the stress introduced from diametrical compression. The effect of these cracks would more likely be seen in tension tests that are difficult to perform with the tablet geometry. The relationship between diametrical breaking strength and percent relative density is shown below in Figure 5.

![Breaking Stress vs. %RD - Copper](image)

**Figure 5. Graph of Breaking Stress vs. %RD of the copper compacts for both ejection methods.**

The effect of ejection was also analyzed by the use of scanning electron microscope images. In the images the effect from ejection can be seen by the number and size of microcracks, as well as the scoring in the surface. Below in Figure 6 the difference between the two ejection types is shown with two different 85% RD tablets.
It is very easy to see the scoring marks left behind from forcing the compacts out of the die in comparison to them falling out. It is also interesting to see that the STRECON ejection seems to have pits, not cracks. These pits are likely air due to the compact not being fully dense. The picture on the right of Figure 6 does not seem to exhibit this behavior because of material being smeared over these openings during ejection. Many cracks can be seen in this smeared layer. Below in Figure 7 a large crack was found to exist in an 85% RD tablet that was ejected in the traditional way.

Figure 6. The surface on the left corresponds to STRECON ejection and the right is regular ejection. Both are 85%RD, 100x magnification, and taken with 10 kV
Again shown in the image above are very apparent gouges and the presence of a large crack in the direction parallel to ejection. Frictional forces on the die wall create the microcracks in this direction as the material drags during ejection. This was a trend that was seen in most of the 85% RD images, but the same cannot be said about the 70% RD samples. The radial stresses experience by a 70%RD tablet would be less, meaning the effect from ejection would be less. This can be explained by an analogy of a tennis ball, if you hold it between your thumb and index finger, the harder you squeeze the further the ball expands radially. The images below in Figure 8 compare two 70% RD compacts ejected by the two different methods.

**Figure 7. 85% RD Tablet 100x Magnification with 5 kV**
Even at 70% RD it is apparent that smearing during ejection has smoothed the surface of the compact. The difference compared to the high density tablets is that the scoring lines seem to be much less apparent and there seems to be less cracks on the surface. Cracks are hard to distinguish because there are more gaps in the matrix due to the lower density.

**CONCLUSIONS**

Though the data from the diametrical compression test does not show a difference in strength according to the ejection type, the scanning electron microscope images demonstrate that there is an effect due to radial stress. The effect from ejection modes for both 70 and 85% RD become apparent when analyzing the images. There are apparent latitudinal cracks on the surface of the 85% RD compacts as well as longitudinal scoring that may also have an effect on the overall toughness of the material when regular ejection is used. Smearing is very obvious in all of the samples that were ejected normally and little to no smearing was seen with the compacts that used STRECON ejection.

The effect of STRECON ejection was not detected physically from strength tests, but visually from scanning electron microscope images. Further failure mode testing would need to be conducted to prove that STRECON dies can be used to strengthen compacts for their applications. Based on this study, it would be expected to see that STRECON ejection does have an influence on the strength,

*Figure 8. The surface on the left corresponds to STRECON ejection and the right is regular ejection. Both are 70%RD, 100x magnification, and taken with 10 kV*
but only in directions that would pull open the microcracks. This would need to be proven through additional experimentation or simulation.

REFERENCES


