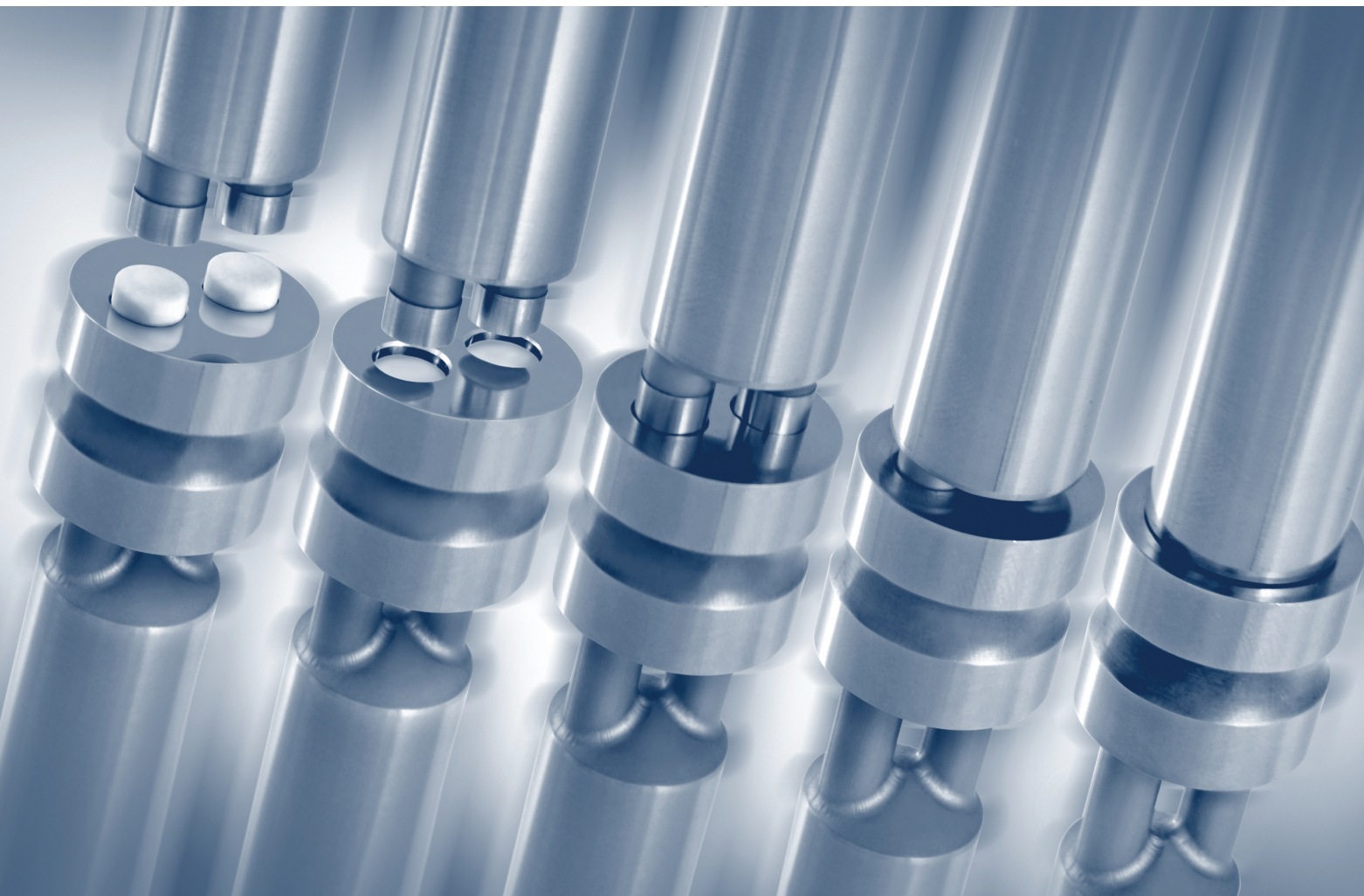

tablet tooling

UNDERSTANDING MAXIMUM
COMPRESSION FORCE

KEVIN QUEENSEN
NATOLI ENGINEERING



As the number and variety of products made on tablet presses grow, manufacturers of tablet presses and tooling continue to advance the science of tablet compression. This article discusses how computer modeling helps determine maximum compression force of tablet tooling.

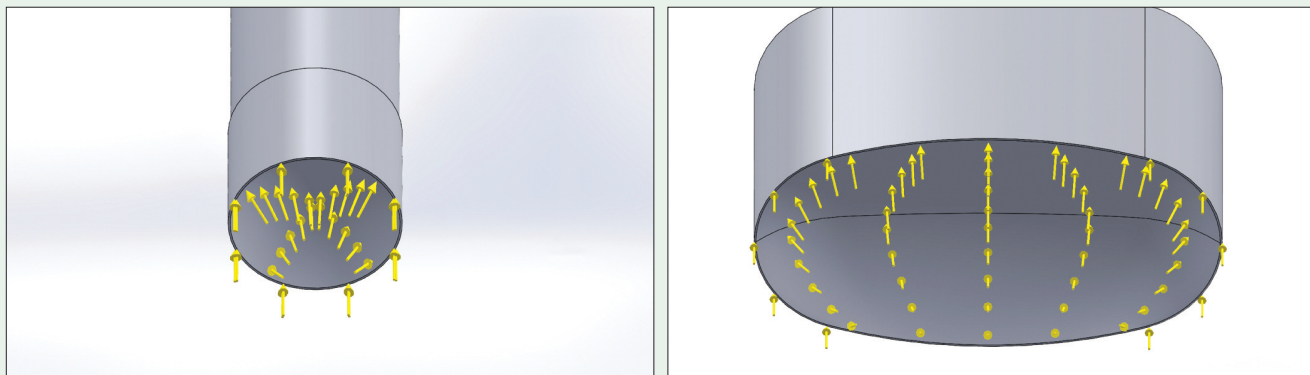
While pharmaceuticals and dietary supplements account for the great majority of tablets, they're also found in the chemical, food, confectionery, and energy industries. Each of these sectors has high standards and each demands well engineered, well made tooling. To meet those demands, tooling manufacturers have turned to computer modeling to refine or replace some of the textbook standards, includ-

ing how to calculate maximum compression force for various tablet configurations.

Manufacturing a high-quality tablet punch starts with high-quality tool steel, and the tableting industry uses many different types, each with unique properties that suit different applications. In the USA, the American Iron and Steel Institute (AISI) sets the standards for tool steels, and for many years, AISI S7 was preferred for many applications because it offers excellent shock resistance and thus good resistance to splitting/shearing stress. It also withstands relatively high compression forces.

FIGURE 1

Normal forces acting on round and oval punch-cup faces



Other tool steels, such as AISI D2, DC-53, K340, and powder-metallurgy (PM) class steels offer excellent wear resistance because they can attain a higher hardness than other steel types and have a high carbide content. Tool steels with a high chromium content, such as AISI 440C and M340, are particularly useful when compressing corrosive or sticky products. The general rule: As the Rockwell hardness of a material increases, wear resistance increases and impact toughness decreases. Some PM-class steels, however, exhibit both excellent wear resistance and relatively high impact toughness due to their unique chemical composition and the distinctive forging/manufacturing process used to make them. Reputable vendors of tablet tooling offer punches and dies made from a variety of tool steels, enabling the vendor to select the best steel, one that exceeds the requirements of the desired compression force and withstands the abrasive, sticky, or corrosive properties of the granulation to be tableted.

Steel strength

Whatever the application and whichever tool steel you use, when calculating maximum tip force, the most important properties to take into account are tensile strength, compressive strength, yield strength, and impact toughness.

Compressive, tensile, and yield strength depend on the chemical composition of the steel and its Rockwell hardness. Compressive strength indicates how well a material—in this case steel—resists deformation in pure compressive loading. Tensile strength refers to the maximum stress a material can undergo when pushed or stretched before it fails. Yield strength—the most important indicator—is the maximum amount of stress a material can withstand before plastic deformation occurs. Impact toughness describes the maximum amount of energy from an impulse or shock loading that a material can withstand. Because each type of tool steel has unique or distinctive mechanical properties, the maximum compression force of each also differs.

Stress concentration

During the compression phase of tableting, forces are applied normally to all surfaces of the cup (Figure 1).

These forces result in stress, which is a function of both the cup's area and its geometric profile. Basic stress relates to the force exerted and the area over which it is applied, but calculating maximum allowable compression force requires comparing maximum stress to the yield strength of a given material. In addition to force and area, stress concentration factors must be factored in. Stress concentration refers to small areas of significantly increased stress caused by sharp transitions in the geometric profile of the cup and/or punch face. Examples include bisects and the blend radius where the embossing meets the cup radius. Punches with stress concentrations have lower maximum compression force compared to tooling that makes plain tablets.

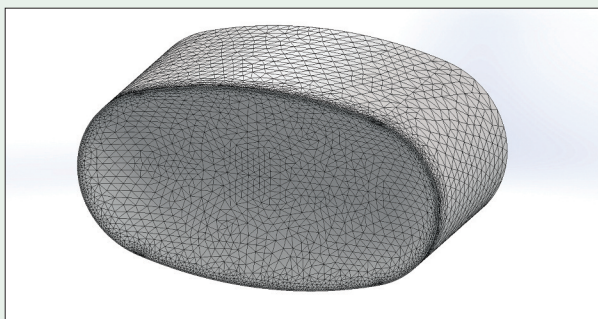
A punch face's land—the flat edge at the perimeter of the punch cup where the cup radius ends—also plays a critical role in determining maximum allowable compression force. Despite the small size of this feature, it's an important factor in calculating how much force a punch tip can withstand before it fails. In general, the larger the land of a tablet or tool, the greater the maximum allowable compression force. In almost all cases, increasing the size of the land of a punch is one of the easiest and quickest ways to increase its maximum compression force. Keep in mind, however, that as the tooling wears, the land erodes and becomes smaller. That's why new punches with unworn lands withstand more force than punches of the same design that have been used for many production runs. That fact also illustrates why proper tooling maintenance is so important: not only does it ensure quality tablets, but it also helps to maintain the mechanical integrity of the tooling itself.

Predictive modeling

Like other manufacturers, many tooling vendors have adopted finite element analysis (FEA) to better understand how different tooling designs affect performance. FEA is a powerful tool, enabling engineers to apply any combination of forces and/or pressures to a solid model and see the result, including the stresses, strains, and displacement, as

FIGURE 2

Mesh created by FEA modeling software



well as other factors related to the safe use of the tooling or any part or assembly associated with it. With FEA, design engineers can analyze complex cup geometry and see where stress concentrations develop and use that information to improve tablet and tool design.

FEA works just as its name implies, by defining discrete elements within a larger model and analyzing them piece-by-piece. To begin, the model is broken down into a finite number of small pieces, the size of which the user controls. This collection of elements is known as a mesh (Figure 2). Next a material, with all the necessary properties defined, is assigned to the model, and the desired force vectors are applied to all surfaces of interest.

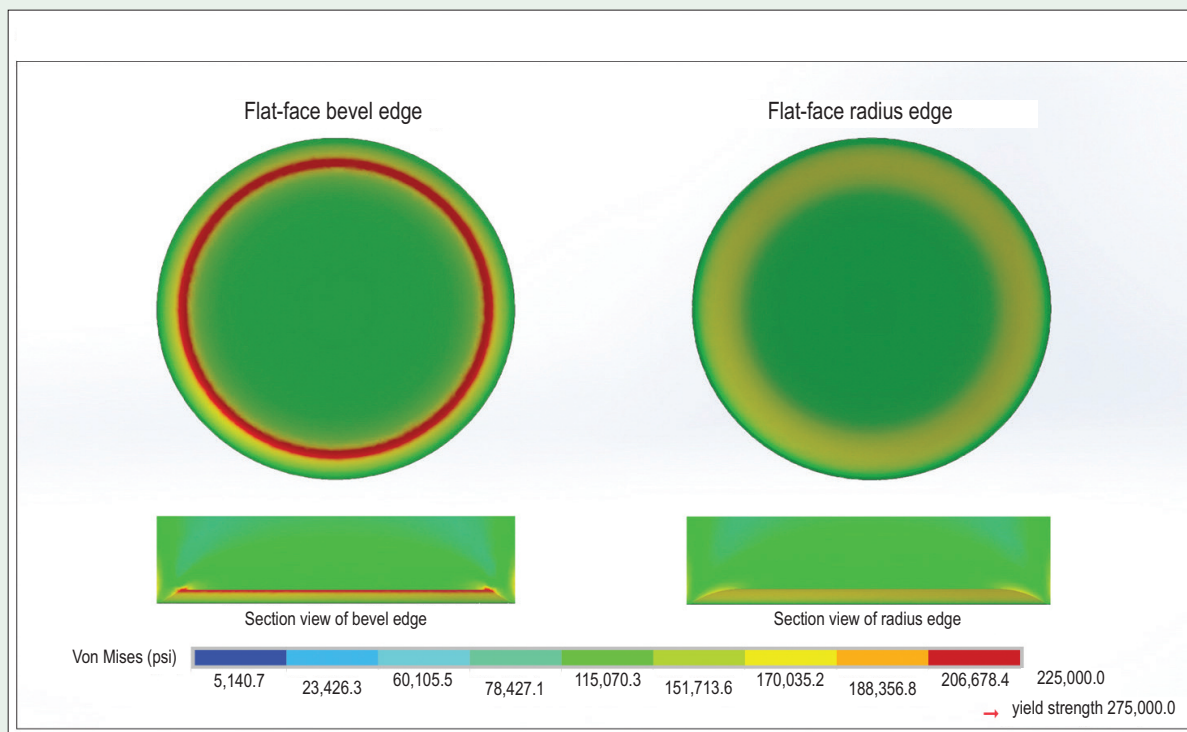
The model is then constrained to simulate how it would act in a real-world installation. Last, a failure criterion is selected, which is a set of values at which the material and part combination would likely fail. With these parameters in place, the analysis begins, and the FEA software examines each element of the mesh to analyze the stress states of the model. The result: a detailed map showing where maximum stresses and resulting failures are likely to occur, enabling engineers to modify the design.

For ductile materials, such as metals, von Mises stress—also called equivalent tensile stress—is generally accepted as the best failure criterion. It states that when an elastically deformable body is subjected to three-dimensional loading, it will develop a complex network of three-dimensional stresses.

Von Mises stress can also be formulated in terms of von Mises yield criterion, which states that, even when none of the three principal stresses exceeds the yield strength, the yield may still be reached as a result of the combination of stresses. This criterion works particularly well when FEA uses a mesh model because it narrows the almost infinite number of degrees of freedom. That is, the calculated von Mises stress combines all stresses into an equivalent tensor value that engineers can compare to a material's known yield strength. Figure 3 shows the von Mises stress distributions of a flat-face, bevel-edge tablet tool and a flat-face, radius-edge tool. Note the stress concentrations (red areas) around the bevel edge of the punch face.

FIGURE 3

Von Mises stress distribution plots: Flat-face bevel edge versus flat-face radius edge



Stress buildup, bent tips, and safety

Note that the maximum compression force that vendors list on tablet and tool drawings account for the fatigue of the tooling, which could be used to make thousands if not millions of tablets. Fatigue is an important consideration because as compression tooling undergoes repeated loading cycles during tablet production, residual stresses build up. This phenomenon—known as fatigue stress—can shorten the life of the tooling. In fact, it's normal for the maximum force that a punch can withstand to decrease over time because of wear and the buildup of residual stress. This means that the tooling can withstand more force when it presses the first tablet than it can when pressing the 500,000th. Ask your vendors if their tooling is designed and engineered for high-cycle loading.

As compression tooling undergoes repeated loading cycles during tablet production, residual stresses build up and must be taken into account.

A final factor to consider when discussing maximum compression force: Bending of the lower punch-tip straights. Generally, it's a concern only when using tooling

with tips 4 millimeters in diameter or smaller. When the tips are that small, cup geometry is unlikely to be the limiting factor when determining maximum compression force. Rather, it will be the propensity of the tips to bend under compressive load. To calculate the maximum compression force of these small-tipped tools, the tooling vendor should determine the compressive load required to bend the tips.

After accounting for all these factors, the appropriate maximum compression force is determined by comparing the calculated stress and force results to the appropriate factor of safety (FOS) for the intended application. The FOS is simply the ratio of the calculated stress to the yield strength of the material. An FOS of two means that the force applied generates a stress in the material that is one-half the yield strength of the material. The FOS value specified depends on the industry and the application, and it can even vary within an industry from one vendor to the next. That's true of the tablet compression industry, where different vendors cite different maximum compression forces. The difference usually stems what value a particular vendor deems an acceptable FOS.

T&C

Kevin Queensen is a technical support engineer at Natoli Engineering, 28 Research Park Circle, St. Charles, MO 63304. Tel. 636 926 8900. Website: www.natoli.com. He holds a BS in mechanical engineering, and his work focuses on designing specialty tablets and tooling.



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