

Inside/Out Light Metals...

Aluminum Extrusion as a Maturing Industry

Understanding Flow Stress and Improving Die Heating

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Introduction

In discussing the evolution of the now maturing extrusion industry, there is a basic truth that should always be considered. The productivity of every extrusion plant can be improved. There are no exceptions to this rule. The single uncontrollable limiting factor in the quest for increased productivity is the maximum speed at which the metallurgy of the alloy being used will permit it to form saleable product with the required profile. Everything else in the entire production system is now controllable.

The technology of light metal extrusion has improved considerably in the past few years. With both die design and production systems increasingly being digitized and improved, extruders can now provide profiles with a level of complexity, dimensional tolerance, and surface finish that was unknown just a few years ago. The ability to understand flow stress, as well as new equipment developments, such as automated die heating systems and improved single cell die ovens, has contributed to the developing maturity of the extrusion industry.

Flow Stress

In the process of aluminum extrusion, there are primarily four main variables—flow stress, billet temperature, ram speed, and the extrusion ratio. Likely, most extruders understand ram speed, billet temperature, and extrusion ratio, which is the cross section area of the billet as it leaves the container, divided by the cross section area of the extrusion as it leaves the die, thus measuring the strain encountered during extrusion. Not all extruders, however, are as familiar with flow stress, what it is, and what it does.

Flow stress is a measure of the aluminum alloy's resistance to being pushed through the die at high temperatures. It is important to the extruder because in the extrusion process, the press or force required to extrude is a function of part geometry, friction through both the container and the die, and the flow stress of the alloy. The flow stress of the alloy is influenced by the following factors: the chemistry and metallurgical structure of the material, the temperature of deformation, the amount of deformation or strain, and the strain rate.

Consider first the effect of temperature and strain rate (extrusion speed) on flow stress (Figures 1-2). It is well known to extruders that as temperature is increased, the pressure required to extrude is reduced. Also, as speed is increased, extrusion pressure increases. Resistance to extrusion is therefore directly related to the flow stress of the alloy, which increases with reducing temperature and increasing strain rate—as can be noted in everyday observations with the response of extrusion pressure to both temperature and speed.

Within a billet, deformation occurs by a process of internal shear. The force or extrusion pressure that causes the alloy to flow is what overcomes the internal resistance or flow stress in the alloy at the given conditions of temperature and strain rate (or the speed of deformation to any given strain). The average strain rate depends on only two factors: the extrusion ratio and speed.

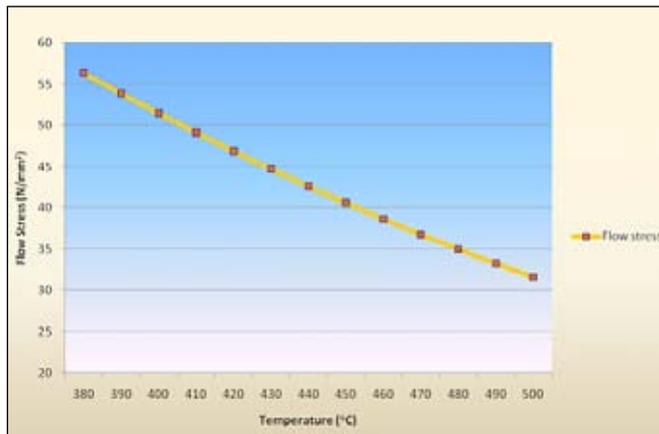


Figure 1. Effect of temperature on flow stress, showing that for 6061 alloy at 19.2 m/min the flow stress increases ~10% with as little as 20°C (68°F) lower temperature.

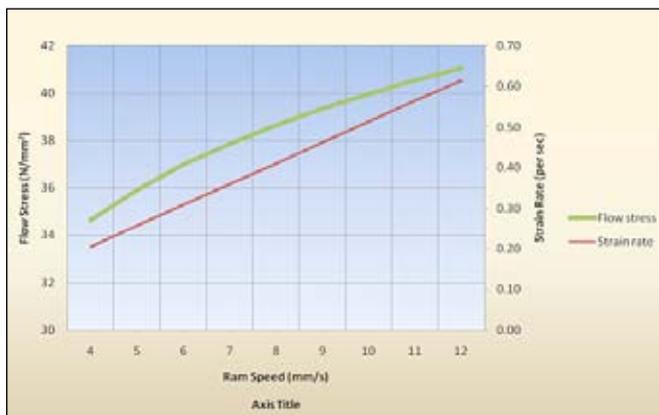


Figure 2. Effect of extrusion speed (or strain rate) on flow stress, showing that for 6061 alloy at 406°C (860°F), flow stress increases ~11% when speed is doubled.

Strain rate, or the deformation given to any strain, varies considerably within a billet, as the alloy deforms and generates the flow pattern to enter the die and form the extruded shape. High localized deformation patterns develop within the billet, especially along the dead metal boundaries in both the container and the die. Resistance to extrusion depends not only on temperature and speed conditions, but also on extrusion ratio and complexity of shape. Extruders know this from experience, but the additional resistance simply results because of higher flow stress under higher strain rate conditions.

The interesting thing from flow stress data is the dependence of flow stress on both temperature and strain rate, and how minute changes in either can have a great effect, which, of course, influences metal flow through the die.

Extruders have long known that if the die begins a production run at less than billet temperature, several billets will usually be run before the temperature completely stabilizes, and steady state temperature conditions occur. There will then be a radial temperature gradient in the die from the center to the edge, as well as in the contain-

er from the top to the bottom, which, in turn, influences the die temperature gradients. This influences how a die behaves and explains why product dimensions or kg/m (lbs/ft) vary from the start of a run to the steady state condition that is established after a number of billets. Also, it explains why, under steady state conditions when there is radial gradient, there is so much speed variation and thickness variation from center to edge of any profile.

The temperature is lower toward the edge of a die, so the flow stress is higher—or in other words the resistance to flow is higher. The applied pressure, or specific pressure, is constant from the edge to center. So material toward the edge of the die being at a lower temperature, must flow slower and at a reduced strain rate to be of equal flow stress to the material flowing faster in the center regions. This is not entirely due to container friction slowing the outer regions down, rather it is caused by temperature gradients, increased localized strain rate (due to container friction effects), and therefore higher flow stress.

The reason die manufacturers open die apertures more in the center is not only to counter die deflection, but also is intended to balance the higher temperature—and thus lower flow stress—encountered in the center regions of the die, which results in higher speed. Certainly, dies deflect, but not to the extent that extruders ignore basic design rules that dictate they should open the aperture in the center. There's something else that dominates, and that something is clearly flow stress or flow resistance differences. Also, thick/thin relationships in dies add complications, where the thicker material is essentially at a lower extrusion ratio than the thin (or at a lower strain rate for equal speed). But predominately, it boils down to an understanding of the effect of temperature and temperature gradients on flow stress.

The first billet die temperature has to be targeted to be at billet temperature, and for challenging dies both the die temperature and initial billet temperature are recommended to be set higher than would be considered necessary for steady state conditions. The practice of using shorter starting billets is not recommended, because of the higher risk of imposing greater stresses on the die, and causing damage. But these are startup conditions only, and the process will reach steady state conditions after a few billets, when the stable temperature gradients are established.

Extruders need to set up the steady state conditions and stable temperature gradients as quickly as possible to avoid scrap from the initial billets. Accordingly, the container liner should be set at 30°C (50°F) below the billet and die temperature. The container plays a critical part in achieving the stable thermal gradient in the die.

Good temperature control is a vital step toward balancing the conditions to provide as near as possible consistent flow stress at the die face. Whatever the temperature condition, the very nature of extrusion will ensure that the alloy will flow at a rate dictated by the combined, and localized, effect of temperature and strain rate. The challenge is getting these conditions to an optimum to allow highest productivity extrusion and least variation in shape, thickness, and microstructure.

An Automated Die Heating System

Light metal extrusion is by definition an exact science. The laws of physics by which it is bound are precise and immutable. The practitioners of this science, however, are not infallible. The human factor can never be completely eliminated from the extrusion process while there is yet an opportunity for improvement, but it can profitably be minimized.

One way to do this is with an automated die heating system, which employs the technology of digitized robotics and expedites the scheduling and heating of the die from the time it arrives from the die shop until it is installed on the press. Although the die will be heated and moved in accordance with a previously prepared formula, the press operator continues to have complete control at all times, and can make any necessary decisions during the process.

First the die is brought and placed in an empty transporting cradle of the heating system by the die handler. The die remains in this cradle and is moved robotically in sequence, until it is placed in the die slide by the operator. Using a bar code scanner or key punch, the die number is entered by the die handler. If there is an existing "best yet" production formula, it will be activated. If not, an initial formula is prepared, and the die will be automatically moved into the scheduling area. The press operator selects which die is to be placed in an empty die oven. The robot then places the die in the oven, where it is heated to the temperature required by the formula. When the operator requests the next die to be run, the robot moves the die from the oven to a heated holding area. Maintaining the temperature of the heated die while it is waiting to be used is critical; if uncontrolled, the die temperature will drop by about 5°C (9°F) every minute. If the temperature of the die is allowed to drop significantly, the flow stress may increase the breakthrough pressure enough to bend or break the die. After the die leaves the heated holding area and is deposited next to the press, the operator moves the die from its cradle to the die slide, using the eyebolt and crane previously employed (thus, requiring no change in existing handling equipment).

A major benefit of the automated die heating system is the fact that time and temperature of each die is monitored and recorded, so that whenever the productivity of a die improves, its production recipe or "best yet" formula can be updated. Once the production formula for a die is entered, human error is minimized and the die is held at operating temperature until use. Other benefits include operator safety, and a major reduction in the amount of floor space required. The press operator remains in charge at all times. The automated die heating system, however, is a valuable tool that helps improve productivity and profit.

The Single Cell Die Oven

It has been determined that in a conventional single cell die oven, heating the die by radiation, the amount of time taken to heat the die is not simply a direct function of the mass of the die. Since the transfer of energy is by radiation, the amount of time taken to bring the die uniformly to the desired temperature depends to a large extent on the amount of surface area of the die that is exposed to direct radiant energy.

Typically, an electrically heated single cell die oven has heating elements on two sides. New die ovens have been developed, however, which have heating elements on all four sides, showing a best time to temperature that is as much as 40% less than a conventional oven. The amount of electricity used, and therefore the cost of operation, also shows a similar reduction.

Conclusion

A new-found working knowledge of flow stress, the advanced technology of an automated die heating system, and enhanced die ovens, all help the extrusion industry achieve an important stage of its evolution that will be reflected in both productivity and profit. By definition, however, extrusion cannot yet be considered a mature industry since ongoing improvement in technology is still anticipated.