WIRE TECHNOLOGY

Process Engineering and Metallurgy

Roger N. Wright

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PROCESS ENGINEERING AND METALLURGY

ROGER N. WRIGHT

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Wire Technology

DEDICATION

To my wife, Patricia, who has learned that every room is an office, and every table is a desk.

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PREFACE

Being in a family with several generations of professional practitioners in metals processing and the teaching thereof, I suppose my writing of this book was inevitable. Even so, I must clearly acknowledge two strong influences outside of the family sphere. The first was the late Walter A. (Al) Backofen, professor of metallurgy and materials science at MIT a half-century or so ago. While I received the benefit of some of his lectures, his major impact was by way of his book *Deformation Processing*, Addison-Wesley, 1972. This book was the first that I am aware of to teach deformation processing with major emphasis on Δ, the shape of the deformation zone. To be sure, Δ or its equivalent was utilized in some of the more enlightened mid-twentieth century wire drawing research (most notably that of J. G. Wistreich) and citations of the importance of deformation zone geometry can be found in the literature of the 1920's. However, Backofen powerfully employed it as a teaching tool, bringing together a considerable array of mechanical analyses, process designs and mechanical metallurgical phenomenology. As a young metallurgist, I assumed that just about everybody used Δ, only to find out that its work-a-day industrial applications had been minimal. In this context, I applied it (arguably even over applied it) every chance that I had, and in the wire industry I believe it has been of significant value. In any case, it is central to much of this book, and I have Professor Backofen to thank.

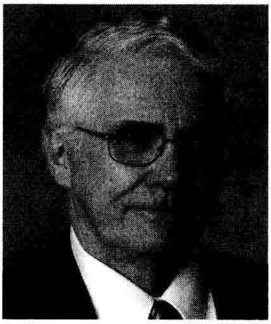
The other influence that I would like to cite was Dr. Alan T. Male, my manager during the years that I spent at Westinghouse Research Laboratories. Alan was, of course, renown for his development of the ring compression test that quantifies friction in forging (a brilliant application of deformation zone geometry, incidentally). Moreover, he had been a faculty member at The University of Birmingham and had an instinctive and synergistic approach to applying rigorous research technique and perspective to industrial processing systems. He, early on, directed my involvement in a wide variety of sophisticated wire processing studies, as well as in the supervision of industrial society seminars and short courses. When I left Westinghouse to join the faculty at Rensselaer Polytechnic Institute in 1974, I had been given a thorough education in wire processing, to go with my broader backgrounds in metallurgy and metals processing.

Addressing the subject at hand, I have written this book in the style of an upper level undergraduate, or possibly graduate level text, acknowledging that one is not likely to find such a course on wire processing, except perhaps in Eastern Europe. This approach has allowed me to use directly much of my experience in technology-focused short courses, as well as my experience in teaching undergraduates and graduate students at Rensselaer. I have written it with the hope that it will be useful for self study and continuing education offerings, as well as serving as a desk reference. At this point in time, I believe that it occupies a unique position in the engineering literature.

Finally, I would like to thank the most helpful staff at Elsevier, Inc., particularly Haley Salter and Kiru Palani, for their patient handling of this, my first, book.

Roger N. Wright, ScD, PE, FASM, FSME

ABOUT THE AUTHOR



Roger N. Wright, professor of materials engineering at Rensselaer Polytechnic Institute, has contributed broadly to the literature in the areas of metallurgy and metals processing, and is active as a short-course lecturer and consultant. Prior to joining Rensselaer, he was a senior staff member at Westinghouse Research Laboratories and at Allegheny Ludlum Steel Corporation. He holds B.S. and Sc.D. degrees in metallurgy from Massachusetts Institute of Technology. He is a registered professional engineer and a fellow of ASM International and of the Society of Manufacturing Engineers.

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CHAPTER ONE

The General Idea

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1.1. CONCEPTS

1.1.1 Drawing

The concept of drawing addressed in this book involves pulling wire, rod, or bar through a die, or converging channel to decrease cross-sectional area and increase length. In the majority of cases the cross section is circular, although non-circular cross sections may be drawn and/or created by drawing. In comparison to rolling, drawing offers much better dimensional control, lower capital equipment cost, and extension to small cross sections. In comparison to extrusion, drawing offers continuous processing, lower capital equipment cost, and extension to small cross sections.

1.1.2 Wire, rod, and bar

In general, the analyses of wire, rod, and bar drawing are similar, and we may use the term **workpiece**, or simply the term *"wire,"* when there is no distinction to be drawn. However, there are major practical and commercial issues to be addressed among these terms. **Bar** drawing usually involves stock that is too large in cross section to be coiled, and hence must be drawn straight. Round bar stock may be 1 to 10 cm in diameter or even larger. Prior to drawing, bar stock may have been cast, rolled, extruded, or swaged

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(rotary cold forged). **Rod** drawing involves stock that may be coiled, and hence may be delivered to the die from a coil, and taken up as a coil, on a block or capstan. Round rod stock will often have a 0.3 to 1 cm diameter, and will often have been cast and/or rolled prior to drawing. **Wire** drawing involves stock that can be easily coiled and subjected to sequential or tandem drawing operations with as many as a dozen or more draws occurring with a given drawing machine. Each drawing operation or "pass" will involve delivery of the wire to the die from a coil on a capstan, passage through the die, and take-up on a capstan that pulls the wire through the die. **Fine wire** drawing typically refers to round wire with a diameter of less than 0.1 mm, and **ultra-fine wire** drawing typically refers to round wire as fine as 0.01 mm in diameter.

1.1.3 Materials

Essentially any reasonably deformable material can be drawn, and the general analysis is the same regardless of the wire, rod, or bar material. The individual technologies for the major commercial materials, however, involve many nuances. The drawing technologies are often divided into **ferrous** (steel) and **non-ferrous** and **electrical** (usually copper and aluminum), although there is specialty production and research and development interest in such high-value-added products as thermocouple wire, precious metal wire, biomedical wire, wire for high temperature service, superconducting wire, and so on.

Apart from the material drawn, drawing technology depends substantially on the materials used for **dies** ("carbide," diamond, tool steel) and on the materials or formulations used for **lubricants** and coatings.

1.2. HOW DOES DRAWING WORK?

1.2.1 Why not simply stretch the wire, rod, or bar?

It can be argued, at least in principle, that some of the objectives of drawing could be achieved by simply stretching the wire with a **pulling force**. The cross section could be reduced and elongation accomplished, but dies would not be needed and the friction and metal flow issues presented by the die could be avoided.

The principal problem with just stretching the wire with a pulling force is the necking phenomenon. Basically, after a certain amount of uniform stretching, all further elongation will be concentrated at a single location (a neck), which will rapidly thin and break. This occurs because the decrease in cross-sectional area eventually weakens the wire more than any strengthening that occurs by work hardening. Heavily drawn wire will have little or no work-hardening capability, and will neck almost at once if subjected to simple stretching. Although some complex "dieless" drawing systems have been invented, simple stretching has only limited application because of its vulnerability to necking.

1.2.2 A simple explanation of the drawing process

In the drawing process, a **pulling force** and a **pressure force**, from the die, **combine** to cause the wire to extend and reduce in cross-sectional area, while passing through the die, as schematically illustrated in Figure 1.1. Because of this combined effect, the pulling force or **drawing force** can be less than the force that would cause the wire to stretch, neck, and break downstream from the die. On the other hand, if a reduction too large in cross-sectional area is attempted at the die, the drawing force may break the wire. In commercial practice, engineered pulling loads are rarely above 60% of the as-drawn strength, and the area reduction in a single drawing pass is rarely above 30 or 35%, and is often much lower. A particularly common reduction in non-ferrous drawing is the **American Wire Gage (AWG)** number, or about 20.7%. Many drawing passes are needed to achieve large overall reductions.

1.2.3 Comparison to other processes

The use of pulling or pushing forces, together with dies or rolls, is common to many deformation processes[1,2], as shown in Figure 1.2. Figure 1.2a illustrates

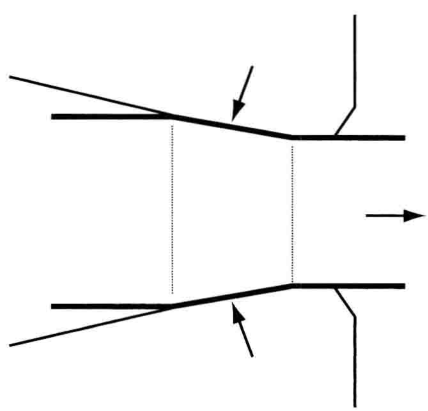

Figure 1.1 Schematic illustration of forces in drawing.

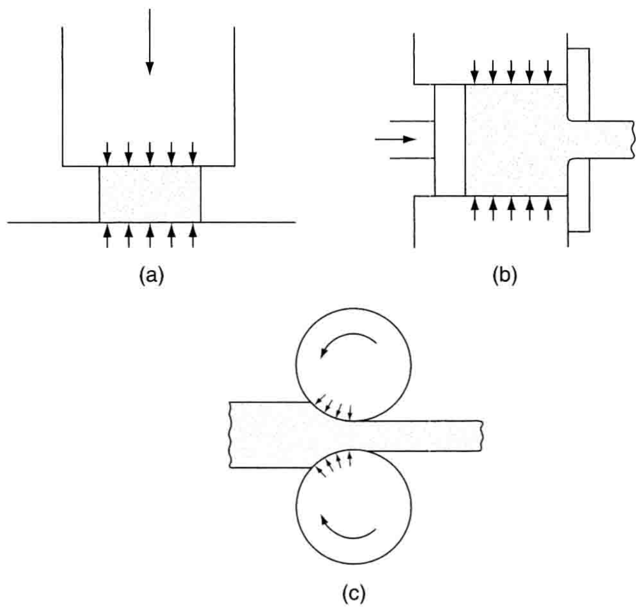

Figure 1.2 Schematic illustration of (a) forces in forging or upsetting, (b) some of the forces in extrusion, and (c) roll motion and roll force in rolling. From G.E. Dieter, *Mechanical Metallurgy*, Third Edition, McGraw-Hill, Boston, MA, 1986, p. 504. Copyright held by McGraw-Hill Education, New York, USA.

the basics of a simple forging or upsetting operation, and Figure 1.2b and c illustrate extrusion and rolling operations, respectively. Many other variations exist. For example, rod or strip can be reduced by pulling through undriven rolls, and so on.

The term "drawing" is used to describe a number of metallurgical processing operations, and when searching titles in the metalworking or intellectual property literature, be careful not to confuse references to *deep* drawing of sheet metal, drawing aspects of forging, or steel tempering operations referred to as drawing, and so on, with the pulling operations outlined in this book.

1.2.4 Overall process hardware

In addition to the die, held in a **die block**, a basic drawing operation involves a **payoff** and a **take-up**, as illustrated in Figure 1.3. Also necessary is a system for applying lubricant to the wire before it enters the die. Figure 1.3 schematically illustrates a **soap box**, which contains a solid powdered-soap lubricant that the wire is pulled through prior to die entry. With liquid

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