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Preface

This book is addressed to both research scientists at universities and technical institutes and to engineers in the metal forming industry. It is based upon the author's experience as head of the Materials Science Department of the Institut für Umformtechnik at the University of Stuttgart.

The book deals with materials testing for the special demands of the metal forming industry. The general methods of materials testing, as far as they are not directly related to metal forming, are not considered in detail since many books are available on this subject. Emphasis is put on the determination of processing properties of metallic materials in metal forming, i.e. the forming behavior. This includes the evaluation of stress-strain curves by tensile, upsetting or torsion tests as well as determining the limits of formability. Among these subjects, special emphasis has been laid upon recent developments in the field of compression and torsion testing. The transferability of test results is discussed. Some testing methods for the functional properties of workpieces in the final state after metal forming are described. Finally, methods of testing tool materials for bulk metal forming are treated.

Testing methods for surface properties and tribological parameters have not been included. The emphasis is put on the deformation of the specimens. Problems related to the testing machines and measuring techniques as well as the use of computers are only considered in very few cases deemed necessary.

Chapters 1 to 6 of the book are a revised translation of the author's German book "Werkstoffprüfung für die Umformtechnik" (M. R. E., Springer-Verlag 1986) whereby the DIN standards have been replaced by the corresponding ASTM standards as far as possible. However, quite a number of testing procedures described in this book have not yet been standardized by the ASTM. Therefore some useful ISO, Euronorm and DIN standards etc. have also been cited.

Though many ASTM standards are not based on the metric system this system has been used exclusively in the book (a table for the conversion of ISO to USCS units has been included in the appendix).

In Chapters 1 to 6 some of the German references that had been cited in the German book have been replaced by publications in English. However, one cannot overlook the fact that in the field of metal forming a very large amount of recent literature has been published either in Germany or in Japan. Therefore it was inevitable to retain many references in German.

In addition to Chapters 1 to 6 a new chapter about testing tool materials for bulk metal forming and a table of comparative materials standards for steels (DIN-AISI-UNS) as well as the description of an unified procedure of upsetting cylindrical specimens have been included.

The author wishes to thank the Director of the Institut für Umformtechnik, Professor Dr.-Ing. Dr. h.c. K. Lange, for supporting and encouraging his work. He also wishes to express his gratitude to the translator, Dipl.-Ing. R. Kuehl M.A., to Mrs. Brigitte Wand for her devoted and careful assistance during the preparation of the manuscript, and to all co-workers of the Institut für Umformtechnik who have contributed to this book directly or indirectly.

Stuttgart, Summer of 1988 Klaus Pöhlandt

Table of Contents

1 Introduction

Symbols

Remark: in the subsequent chapters only new symbols or such ones that have been used in a different meaning have been listed. Most of the symbols agree with those in the "Handbook of Metal Forming" /1.1/ which in some cases are based on ISO R 31/III, IV and V and on CIRP "Recommended Symbols in Forming Technology" (1976); in cases when they are related to materials testing, however, they are mainly based on the ASM Metals Handbook, Vol. 8 /1.2/, rather than on ISO R 82 or ISO/TC 17 N 1093. To a large part, these symbols agree with those used in the ASTM standards.

Concerning the symbols for the strain resp. equivalent strain, a rigorous treatment like that one in the "Handbook of Metal Forming" /1.1/ has to make a distinction between the slab theory where the equivalent strain usually is denoted by the symbol $\bar{\varphi}$ and the v. Mises theory where the symbol $\bar{\varepsilon}$ is used. For the purpose of this book, however, which is intended to be used by experimentalists rather than by theoreticians it is sufficient to use the symbol $\bar{\varphi}$ for the equivalent strain in all cases; this can be applied not only to the uniaxial tensile and upsetting tests but also to the torsion test on round bars and to the plane torsion test when the local deformation of a given volume element is considered.

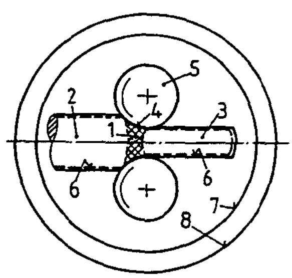
CVN	Charpy notch energy
$\bar{\varphi}$	equivalent strain
HB	Brinell hardness
HRC	Rockwell C hardness
HV	Vickers Hardness
K_{Ic}	fracture toughness
r	normal anisotropy
Δr	planar anisotropy

RA	percentage reduction of area at fracture
R_a	average roughness deviation from mean surface
R_p	smoothing depth
R_t	peak-to-valley height
R_z	ten point height of irregularities
S_u	ultimate tensile strength
S_y	yield strength
$S_{y0.2}$	yield strength at 0.2% non proportional elongation
$\sigma_1;\sigma_2;\sigma_3$	principal stresses
σ_f	flow stress
σ_m	mean normal stress

1.1 The System of Metal Forming

The structure of this book is related to the system of metal forming which is illustrated by Fig. 1.1 /1.3/. The theoretical background of a consideration of such a system is given by the theory of systems 1.4/. In metal forming the theory of systems has been mainly applied to tribological problems /1.5/ up to now.

This book deals with the elements 2, 3, 5 and 6 of the system shown in Fig. 1.1. Testing methods to be applied during metal forming processes as well as tribological testing methods and problems related to metal forming machines have not been examined.



1. plastic zone
2. material properties before forming
3. material properties after forming
4. contact zone
5. tool
6. workpiece and surrounding atmosphere
7. forming machine
8. factory

Fig.1.1. The system of metal forming using rolling as an example /1.3/

This book comprises only a brief overview of testing methods which is not meant to be complete. Many details have been omitted, but each chapter includes a long list of references which facilitates the search for additional information.

To begin with, the material before the metal forming process is dealt with in annealed condition thus having the initial strain $\bar{\varphi} = 0$. Testing methods are described which provide a quantitative measure of the forming behavior of the material. This includes the determination of flow curves as well as of the plastic anisotropy and of the limits of formability.

In Chapter 6 the material or the workpiece after the metal forming process and its functional properties are looked at and in Chapter 7 testing methods of tool and die materials for bulk metal forming are described.

1.2 The Material before the Forming Process

1.2.1 Overview

As a rule it can be assumed here that the material to be used for sheet metal forming is sheet metal while the material for bulk metal forming is either bar or sheet metal. Therefore the material for sheet metal forming usually has orthotropic symmetry whilst the material for bulk metal forming may be either orthotropic (this holds not only for sheet metal but also for bars of rectangular cross section), or axisymmetric. In industrial metal forming anisotropy plays a greater role for orthotropic than for axisymmetric materials (see also Sec. 3.9).

The most important properties which characterize a material before the forming process have been listed in Fig. 1.2. These properties may be subdivided into those which are related to the forming behavior (on the left side of Fig. 1.2) and into more general properties which may perhaps enable an estimation of the properties of the workpiece after metal forming (right side).

As a third group, properties which allow for a metallurgical interpretation of the material behavior are listed on the bottom of Fig. 1.2.

Some properties cannot be clearly allotted to one of the three groups meaning that several choices are of an arbitrary nature.

The testing methods to be described in this book are not restricted to any special metal forming process. However, in general they refer to production of finished workpieces rather than of semi-finished products.

Testing methods related to "chipless" cutting such as fine blanking are not included.

Properties related to forming behaviour	Properties without direct correlation to forming
Stress strain curve stress strain curve $\sigma_f(\bar{\varphi})$ yield strength S_y ; $S_{y0,2}$ ultimate tensile strength S_u n - value	**Hardness** HV, HB, HRC **Charpy notch energy** CVN
Plastic anisotropy normal anisotropy r planar anisotropy Δr	**Fracture toughness** K_{IC}
Forming limits uniform elongation ε_u reduction of area RA upsettability Erichsen cupping depth	**Wöhler curve** LCF behaviour **Resistance against corrosion**
Surface properties roughness R_a , R_p , R_t , R_z chem. + phys. surface properties	
Metallurgical properties	lattice structure, micro structure, phases, impurities, precipitations, grain size, texture (orientation distribution)

Fig. 1.2. Overview of material properties before metal forming

1.2.2 Testing the Forming Behavior

Knowledge of both the stresses occurring in the plastic zone during a metal forming process and also of the resulting forces is a prerequisite for the design of metal forming tools and machines.

The stresses depend on the plastic properties of the workpiece material, on friction in the interface between workpiece and tool and on the geometry of the system. These stresses can be calculated using the methods of the theory of plasticity if the forming behavior of the metal is known. The forming behavior is quantitatively described by the flow curve or the yield locus and the forming limits of the material. To determine these properties the tensile test is applied /1.6 to 1.15/. This test is also highly favored in standardization. However, the strain to fracture of metals is higher under compressive stress than under tensile stress /1.16, 1.17/ (see also Fig. 1.3). Therefore the upsetting or the torsion test is preferred if the flow curve shall be determined for high strains.

All these testing methods are described in Chapters 2 and 3.

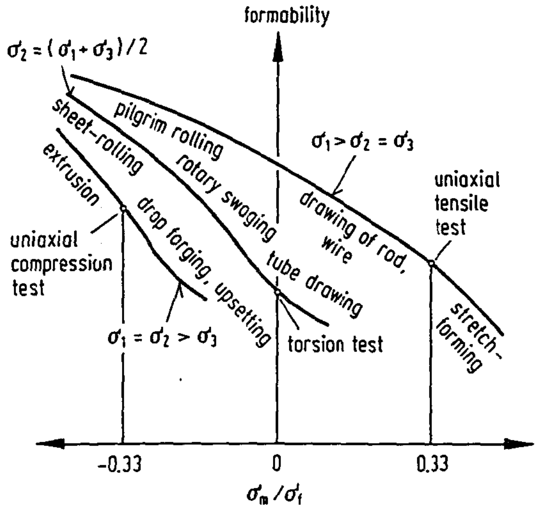


Fig. 1.3. Dependence of forming limit on mean normal stress (schematic) /1.16/

1.2.3 Further Testing Methods

The forming behavior of a material is also affected by its surface and boundary properties. The determination of these properties is beyond the scope of this book. Therefore only some general information shall be given here.

The surface is primarily characterized by its microgeometry, i.e. its properties of roughness /1.18 to 1.22/. In addition a surface is characterized by chemical /1.23,1.24/, physical and mechanical properties /1.25 to 1.28/.

The material properties which are listed on the right side of Fig. 1.2 cannot be used as a direct measure of the forming behavior (though some of them correlate with those on the left side): technological properties such as hardness /1.29 to 1.31/ and the impact strength /1.32/, the fracture toughness /1.33/ and the creep behavior /1.34/. Experiments for testing the fatigue behavior and the corrosion resistance are treated in Chapter 6.

All these tests, including the last ones, are of some interest even before forming since they allow for a first estimation of the properties of the workpiece after metal forming.

Many of these testing procedures have been standardized.

Let us now consider the properties which are listed at the bottom of Fig. 1.2. The structure of materials is investigated by the classical methods of metallography /1.35 to 1.44/ as well as by more sophisticated methods such as X-ray texture analysis /1.45, 1.46/ or electron microscopy /1.47, 1.48/. The investigation of materials faults and surface defects is described in /1.24, 1.49/.

As an example of the correlation of structure properties with formability the effect of pearlite content shall be mentioned: the greater the volume content of spherical pearlite, the greater the reduction of area in the tensile test /1.50/.

1.3 Concluding Remarks

In industrial use flow curves and other properties related to forming behavior are always determined by experiments since theoretical calculations are not accurate enough. The collection of experimental data such as in /1.51, 1.52/ (see also Chapter 4) enables a better estimation than theoretical calculations. However, since data collections hold only for those conditions of heat treatment and structure for which they have been determined, not even they can replace the determination of flow curves by tests.

Contrary to the determination of material properties after metal forming (see Chapter 6) the determination of flow curves and ductility parameters usually does not cause problems of spatial resolution since the material to be tested is a macroscopically homogeneous semi-finished product.

1.4 References

1.1 (Ed.) Lange, K.: Handbook of Metal Forming, New York, NY: McGraw-Hill, 1985.

1.2 (Ed.) Newby, R.: Metals Handbook, Vol. 8: Mechanical Testing, 9th Ed., Metals Park, Ohio: American Society for Metals (ASM), 1985.

1.3 Lange, K.; Wilhelm, H.: Interaction between Work Materials and Forming Processes, Annals of the CIRP 25/2 (1976), pp. 531-537.

1.4 V. Bertallanfy, L.: General Systems Theory, London: Penguin, 1971.

1.5 Czichos, H.: Tribology, Amsterdam/Oxford/New York: Elsevier, 1978.

1.6 ASTM E 6-85a: Standard Definitions of Terms Relating to Methods of Mechanical Testing, 1985.

1.7 ASTM E 8-85b: Standard Methods of Tension Testing of Metallic Materials, 1985.

1.8 ASTM E 8M-86a: Standard Methods for Tension Testing of Metallic Materials (Metric), 1986.

1.9 ASTM A 370-87a: Standard Methods and Definitions for Mechanical Testing of Steel Products, 1987.

1.10 ASTM B 557-84: Standard Methods of Tension Testing Wrought and Cast Aluminum and Magnesium Alloy Products, 1984.

1.11 ASTM B 557M-84: Standard Methods of Tension Testing of Wrought and Cast Aluminum and Magnesium Products (Metric), 1984.

1.12 ISO 6892-1984: Metallic Materials - Tensile Testing, 1984.

1.13 Euronorm 2-80: Tensile Testing on Steel (Revision), 1980.

1.14 ASTM E 83-85: Standard Practice for Verification and Classification of Extensometers, 1985.

1.15 ASTM E 1012-84: Standard Practice for Verification of Specimen Alignment under Tensile Loading, 1984.

1.16 Stenger, H.: Dependence of the Forming Limit of Metals on Stress (in German), Thesis, TH Aachen, 1965.

1.17 Vater, M.; Lienhart, A.: Dependence of the Forming Limit of Metals on Stress at Various Temperatures and Strain Rates (in German), Bänder Bleche Rohre 13 (1972), pp. 387-395.

1.18 Euronorm 49-72: Roughness Measurements on Cold Rolled Flat Products without Coating, 1972.

1.19 Peters, J. et al.: Assessment of Surface Topology Analysis Techniques, Annals of the CIRP 28/2 (1979), pp. 539-554.

1.20 Bodschwinna, H.: Effect of the Stylus Geometry on Industrial Roughness Measurements (in German), Tech. Messen 47 (1980), pp. 21-28.

1.21 Sayles, R.S.; Thomas, T.R.: Measurements of the Statistical Microgeometry of Engineering Surfaces, Trans. ASME, J. Lubr. Eng. 101 (1979), pp. 409-418.

1.22 Droscha, H.: Fully Automatic Surface Testing of Flat Material Using Path Scanning with Lasers (in German), Metall 31 (1977), pp. 1084-1086.

1.23 Storbeck, F.; Edelmann, Chr.: Surface Analysis Methods (in German), Technik 33 (1978), pp. 226-230.

1.24 Kollek, H.: Methods for Fast Detection of Impurities in Metal Surfaces (in German), Metall 33 (1979), pp. 247-250.

1.25 Oehler, G.: Sheet Metal and its Testing (in German), Berlin/Göttingen/Heidelberg, Springer, 1953.