Preface

We are pleased the high demand for ”Leveling with Roller Levelers” has remained strong for over 20 years. With continued strong demand, we strive to raise the standard on leveling technology.

Now, 80 years after ARKU was founded, we're pleased to announce publication and release of the fourth edition of ”Leveling with Roller Levelers”.
This new edition is filled with color illustrations and a modern layout. We've revised ”Leveling with Roller Levelers” to meet the needs of today's readers.

The topic of sheet leveling is more current than ever. Leveling improves the quality of sheet metal processing. The improved tolerances in the flatness of sheet metal parts and coils are obvious.
Less obvious are the favourable distribution of residual stresses in the material, which stabilizes the material for the subsequent processes like folding, bending and roll forming.

We would also like to take the opportunity to thank Prof. Dr.-Ing. Horst Bräutigam. For nearly 30 years, the author has skillfully combined science and application.

Your feedback and constructive criticism is crucial for ARKU to maintain our position as your leveling experts for the future.

We look forward to hearing from you!

Your Albert Reiss

Baden-Baden, July 2009

Imprint:
The ARKU series appears in own publishing of the company
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1th edition 2009
ISBN 978-3-8343-3144-1

Design: Werbeagentur Rommel & Frank, Baden-Baden
Manufacturing: Vogel Business Media GmbH & Co. KG, Würzburg

Baden-Baden in July 2009

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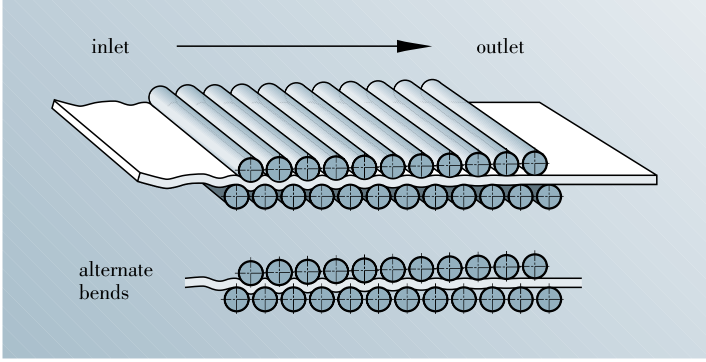
1. Introduction

Despite the widespread use of roller levelers, little is known about the technology behind this type of machine. To shed light on the subject, and explain what happens during the leveling process on roller levelers, I have put together the following information.

Fig. 1.1 Mode of action



In this context I have put forward the effort to search through relevant technical literature such as the Dubbel Handbook of Mechanical Engineering and the Hütte Handbook for Engineers to find information on the leveling process as performed with roller levelers. The small amount of information, if any, provided in these works only explains the mode of operation pictured in **Fig. 1.1** roughly as follows.

”Sheet metal is normally leveled on levelers. The sheets are subjected to alternating bends. The depth of the bends continually decrease in size as the sheets run through the machine from the inlet to the outlet.”

You cannot help feeling that some crucial information is missing from this explanation to understand the process better.

Perhaps the following classification of the roller leveling method can help:

”Roller leveling is classified under bending in the field of forming technology. It is a bending process with rotating tools, whereby the roll axes can be aligned either perpendicular or inclined to the bending plane.”

This information may not be much more illuminating, but taken together the two statements make one thing clear:

”The process material is bent!”

For this to happen, however, forces have to be applied to the material by the leveling rollers.

As the next step toward understanding the leveling principle we should consider the effects of these forces on the process materials, which normally are made of metal.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Principles of materials science

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2. Principles of materials science

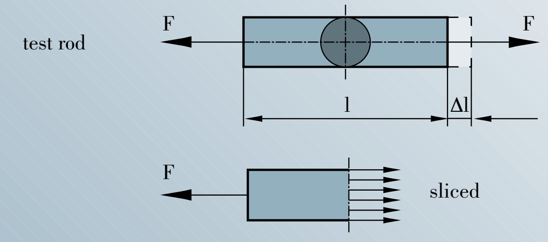
Therefore, we now want to look into the question of how metallic objects behave when they are subjected to a load. In this case our considerations will be limited to applications of force which result in tensile stress, compressive stress and bending stress.

2.1 Tension and compression

A series of predefined tests based on purely phenomenological methodology is normally performed to analyze the behavior of objects under load. The *tensile test* presented in **Fig. 2.1** supplies the most important characteristic: values for assessing a material.

In the tensile test a test rod with cross-section A is loaded with a tensile force F. Depending on the magnitude of this tensile force, the rod stretches by the amount Δl as indicated in the illustration.

Fig. 2.1 Tensile test



$$\sigma = \frac{F}{A} \quad ; \quad \varepsilon = \frac{\Delta l}{l}$$

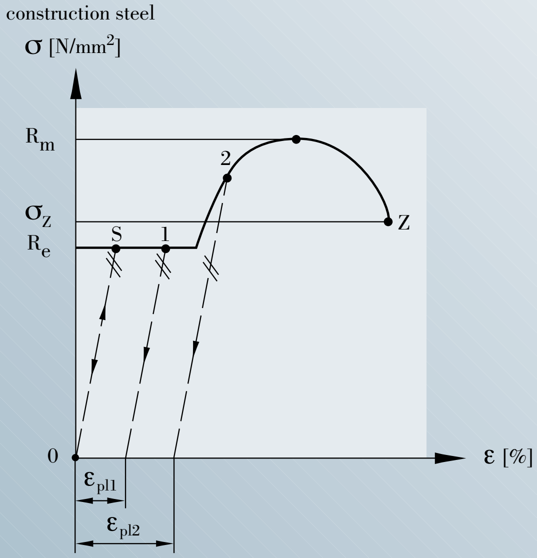
F = tensile force [N]
A = cross section [mm^2]
Δl = change in length [mm]
l = sample length [mm]
σ = tension [N/mm^2]
ε = elongation [1]

If you imagine the object cut open somewhere perpendicular to the tensile force F, then said force is distributed inside the object over the entire cross-sectional area. This distribution is referred to as *stress* and is indicated by small arrows distributed over the cross-section.

In correlation with the external tensile force F, this stress is referred to as the tensile stress σ. It is the force F in relation to the test specimen cross-section A in numerical terms.

It is customary to relate the change of length $\Delta 1$ to the original test specimen length 1. The ratio of $\Delta 1$ to 1 is referred to as the *elongation* ε.

Fig. 2.2 Result tensile test



R_e = yield point
σ_Z = rupture strength
R_m = tensile strength

What you now get from the tensile test in purely qualitative terms is the simplified result presented in **Fig. 2.2**, which is valid for example for a standard *construction steel*. In this figure the stress σ is plotted as a function of the elongation ε.

Let us first consider the zone marked by the straight line OS. If the forces or stresses are kept below the limit value R_e of the *yield point*, then only elastic strains occur. After these stresses are removed, the strains disappear completely and the object springs back. Stress and strain are directly proportional to each other, and the relationship is expressed by *Hooke's Law* in the equation.

$$\sigma = E \cdot \varepsilon$$

The proportionality constant E is the *modulus of elasticity* of the material.

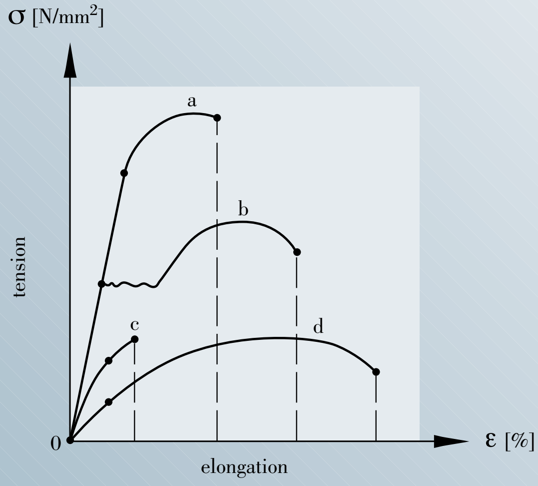
If the stress is increased so much as to reach the yield strength Re, then the *yield range* of the material is entered. This zone is marked by the horizontal straight line. The elastic strains are now accompanied by measurable plastic strains. Hence elastic and plastic strain fractions exist side by side, resulting always in a total strain.

$$\varepsilon_{total} = \varepsilon_{el} + \varepsilon_{pl}$$

Spring-back also occurs, for example, if a test specimen is unloaded from point "1". The elastic strain returns to zero along the dot-and-dash line parallel to the Hookian straight line, but a plastic strain ε_{pl1} arises as a permanent strain of the test rod.

This yield range characterized by the yield strength Re is now followed by the so-called *hardening range*. Here the stress increases with homogenous straining of the specimen until the maximum value, the *tensile strength* Rm, is reached. Then the specimen necks with a local load dip and fractures at point Z, the *rupture strength* σ_z.

Fig. 2.3 Hardening curve metallic material



a: brittle steel
b: mild steel

c: gray cast iron
d: copper

If a specimen is unloaded for example from point "2" in the hardening zone, then the elastic elongation returns to zero and ε_{pl2} arises as a permanent elongation.

As is evident from **Fig. 2.3**, not all metallic materials display the *hardening curve* just shown.

The hardening curves for a brittle steel, a soft steel, grey cast iron and soft-annealed copper are presented in this figure.

All the curves have a more-or-less distinctive linear starting zone. In other words a Hookian straight line. Brittle steel, grey cast iron and copper have practically no yield point, i.e. the transition from the elastic to the plastic-plastic deformation zone is continuous. With such behavior the yield point R_e is replaced by the proof stress $R_{po,2}$. This is the stress which gives rise to a permanent strain of 0.2 %. Compared to copper or soft steel, brittle steel has a hardly distinctive plastic zone. Grey cast iron displays practically no noteworthy plastic deformation. Soft steel displays the behavior already discussed at the beginning.

It is also important to know how a material behaves under compressive loading in practice. In this case, the *compression test* supplies the characteristic values needed for assessing a compressive stress.

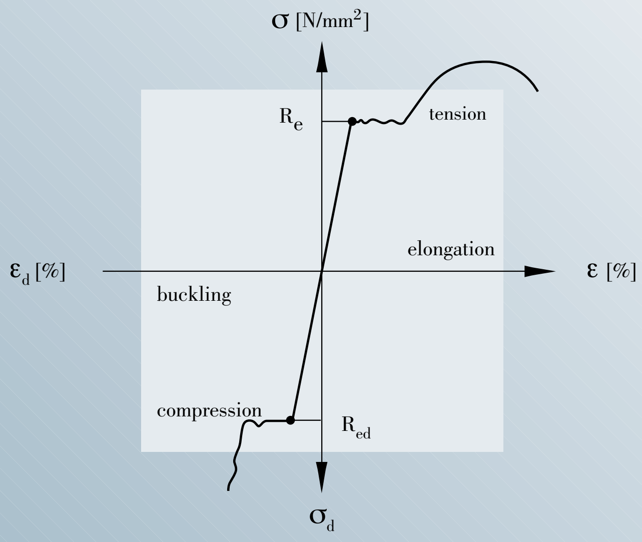
Fig. 2.4 shows the hardening curve for tension and compression, again using the example of a standard structural steel.

The compressive stress σ_d affects a shortening, i.e. compression ε_d of the specimen. As a rule, the ratio of σ_d to ε_d is the same as in the tensile test, namely the modulus of elasticity E. In other words, Hooke's Law also applies in the compression zone.

In the compression zone the yield strength R_e is replaced by the *compressive yield point* R_{ed}, which in the case of ductile materials characterizes the beginning of plastic deformations. R_e and R_{ed} concur as a rule.

A value for the compressive strength corresponding to the *tensile strength* can be determined only for brittle materials. A ductile material can be crushed practically without destruction.

Fig. 2.4 Hardening curve for tension and compression



Hookian straight line:

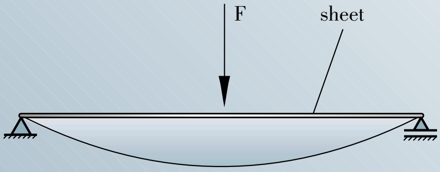
$$\frac{\sigma_d}{\varepsilon_d} = \frac{\sigma}{\varepsilon} = E$$

After this review of loading by tension and compression we now want to consider loading by bending.

2.2 Bending

Fig. 2.5 shows a straight piece of sheet metal which is supported at both ends and loaded at the centre by a force F acting perpendicular to it. Under the action of the force, as a *bending moment*, the metal sheet bends as indicated by the thin line and stresses arise.

Fig. 2.5 Bending load

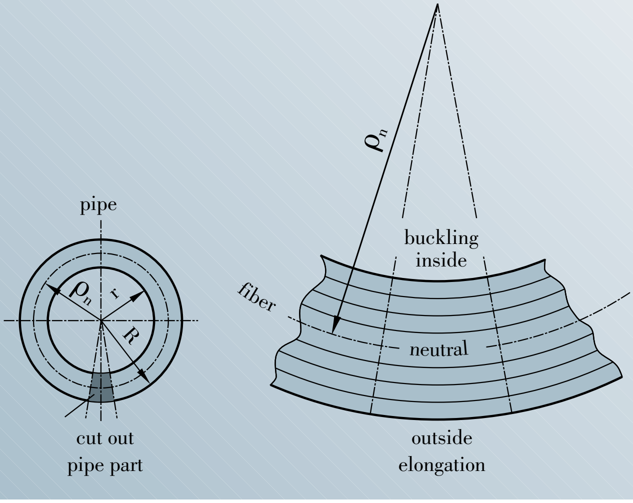


If we focus on a bent piece of the metal sheet as shown in **Fig. 2.6**, then the following applies:

Inner-lying fibres of the material are compressed; outer-lying fibres are elongated. In between is a fibre which is neither compressed nor strained. This fibre is referred to as a *neutral fibre*.

For better understanding let us consider the tube with outer radius R and inner radius r drawn along side. It is clear that the

Fig. 2.6 Bend part

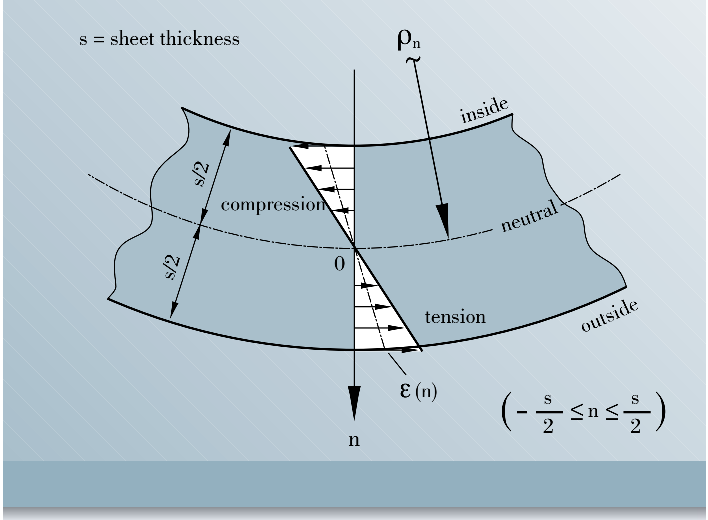


inner circle with radius r has a smaller circumference than the outer circle with radius R. In relation to the circle with radius ρ_n lying in between we can say that the inner circle is compressed and the outer circle is elongated.

Of course, what applies for the tube as a whole must also apply to a piece cut out of the tube. In terms of our bent piece of metal sheet, ρ_n is the current bending radius of the neutral fibre.

Fig. 2.7 presents the stresses and elongated which arise during the bending. It is assumed that the neutral fibre runs

Fig. 2.7 Elastical bending load



elongation: $\varepsilon(n) = \frac{n}{\rho_n}$

edge elongation: $\varepsilon_R = \pm \frac{s}{2\rho_n}$

Hooke‘s law: $\sigma = E \cdot \varepsilon$

stress: $\sigma(n) = E \cdot \varepsilon(n)$

edge stress: $\sigma_R = E \cdot \varepsilon_R = \pm E \cdot \frac{s}{2\rho_n}$

in the middle of the cross-section. The strains and compressions of the individual fibres increase linearly with the distance from the neutral fibre. This relationship is described by the above equation where n is the distance from the neutral fibre. It should be noted that compressions are negative strains.

Hooke's Law applies for elastic loading, i.e. stress and elongation are linked together in a linear relationship. The result is a stress curve (called the *bending stress distribution*) with a linear distribution according to the elongation. The inner-lying compressed fibres are exposed to a compressive stress whereas the outer-lying strained fibres are exposed to a tensile stress. At the edges the stresses and elongation are greatest in terms of quantity and they are referred to as *edge stresses* σ_R and *edge elongation* ε_R.

It should be noted that the neutral fibre then lies in the middle of the cross-section if no additional tensile or compressive load exists along with the bending load.

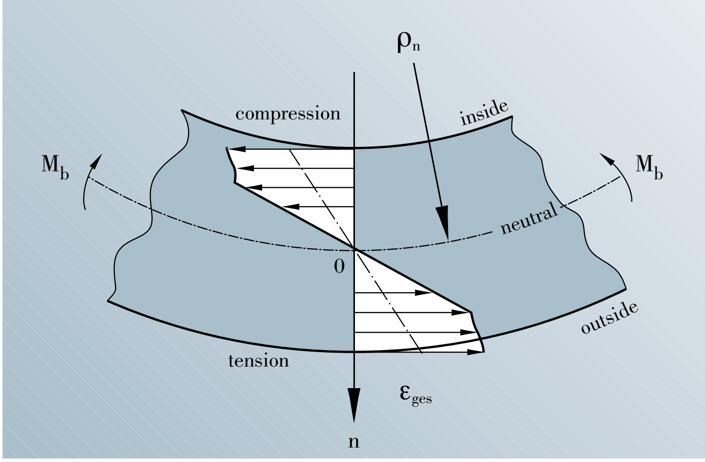
If the maximum values of the edge stresses σ_R remain under the yield strength R_e, then the bent part springs back to its original straight position after the force F is removed.

If the force F is increased (and with it, it's bending moment M_b) such that the above limit value R_e is reached and exceeded, then plastic elongation arise first in the edge fibres. As the bending moment increases, so deeper lying fibres are gradually affected and are likewise plastically deformed. However, the plastic deformation is always hindered by fibres lying further inside which are still elastically deformed.

This *elastic-plastic bending load* has the stress and elongation characteristic presented qualitatively in **Fig. 2.8**.

It is evident that a stress increasing linearly with the distance from the neutral fibre exists only in zones near the middle of

Fig. 2.8 Elastic-plastic bending load



the metal sheet. In the edge zones there arises the yield stress which corresponds to the respective total strain.

The dot-and-dash line shows the characteristic of the total longitudinal elongation ε_{total}.It continues to increase linearly with the distance from the neutral fibre.

If the force F is now removed, the sheet metal will again spring back but will no longer reach its original straight position. A permanent bend with corresponding *residual stresses* is formed.

Conversely, such a bent metal sheet can be restored to its flat condition by corresponding counter-bending with due account for spring-back. This is a decisive point - missing up until now - for our understanding of the working principle:

”Counter-bending with consideration for spring-back!”

In other words, the process of bending and counter-bending corresponds to the working principle of roller levelers. It requires the yield point of the process material to be exceeded while, at the same time, ensuring the material is not damaged in any way. However, damage easily arises, for example with brittle materials, because cracks can develop on the surface from bending beyond the elastic limit.

From this, it is clear that materials with pronounced yield point and with a sufficiently large gap between yield strength and tensile strength are suitable for leveling.

As a rule of thumb we could say:

"What can be bent
can also be leveled!"

Now we want to leave our excursion into materials science and turn to the question of the interaction between *leveler* and the *material to be leveled*.