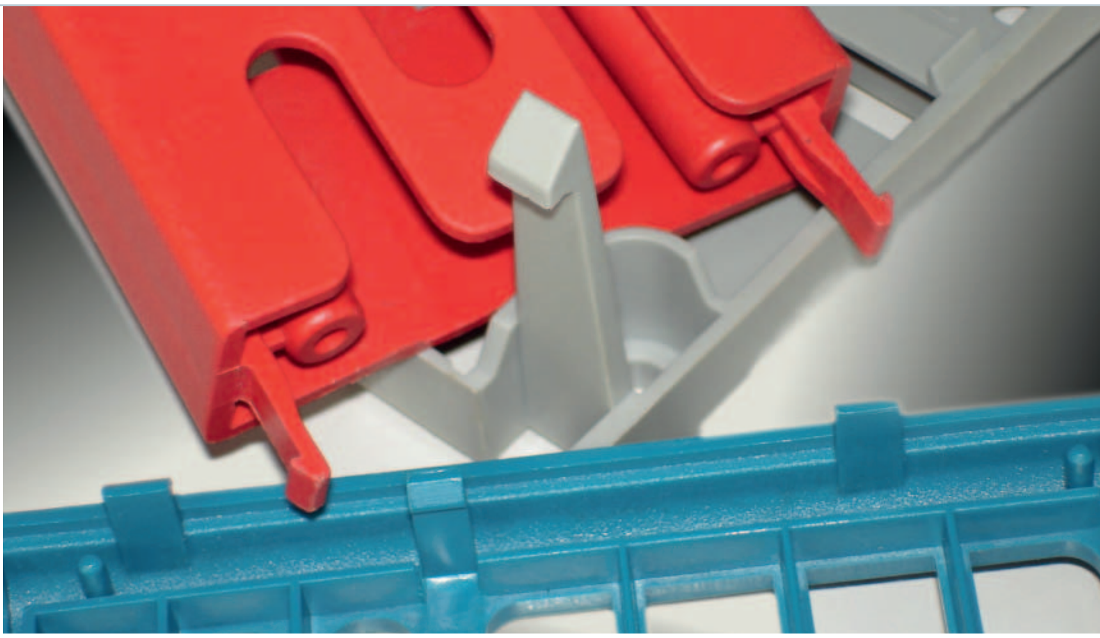

Each discontinuous transition between two different cross-sections of a bending beam results in a notch effect. This is true also when attaching a snap-fit hook to a part

The Notch Effect in the Junction of Snap Hooks

Design. The article describes the effects on stresses and strains in passing through the transition in cross-section and on the deflection or stiffness of the snap hook for different types of junction to a structural part. It also provides simple formulas for calculating this notch effect when designing. The basis of this investigation is a systematics of the possible types of junction developed specifically for this purpose.

PE103823

JOHANNES KUNZ
MARIO STUDER

The junction of a snap-fit hook to a plastic part is generally a critical point of this important element of joining technology. It is here that the bending moment is greatest and the notch effect at the transition makes this situation considerably more critical. When incorrectly designed or as a result of careless handling overloading may occur here that impairs the functioning of the snap joint or even results in its failure due to the snap-fit hook breaking off. Accordingly, in the widespread design recommendations reference is rightly made to this problem [1–5]. Details on methods of calculation or at least estimation, however, form the exception [6].

Threefold Effect of the Junction

Each discontinuous transition between two different cross-sections of a bending beam results in what is referred to as a notch effect. One of these also occurs when attaching a snap-fit hook to a part. It manifests itself in local peaks in stresses and strains. These peaks are inversely proportional to the radius of curvature in the transition. Thus, an effectively lacking radius would result theoretically in infinitely high stresses and hence in failure of the part. Accordingly an adequate curvature of the transition is indispensable. As a result, however the snap-fit hook undergoes a certain stiffening. The design of the junction to the part, therefore, has a threefold effect, that is to say a peak in stress, a peak in strain as well as an increase in rigidity.

A design in line with the loads operating aims at the most uniform possible distributions of stress and hence at large radii of curvature in the junction. On the other hand, for production reasons the rounding should be as low as possible in order to keep accumulations of mass within acceptable limits. This conflict in objectives can only be managed by a compromise in the form of optimal radii. Their determination primarily requires quantitative data on the notch effect. Obtaining these was the objective of the studies [7, 8] whose results are reported here.

Translated from Kunststoffe 7/2007, pp. 46–51

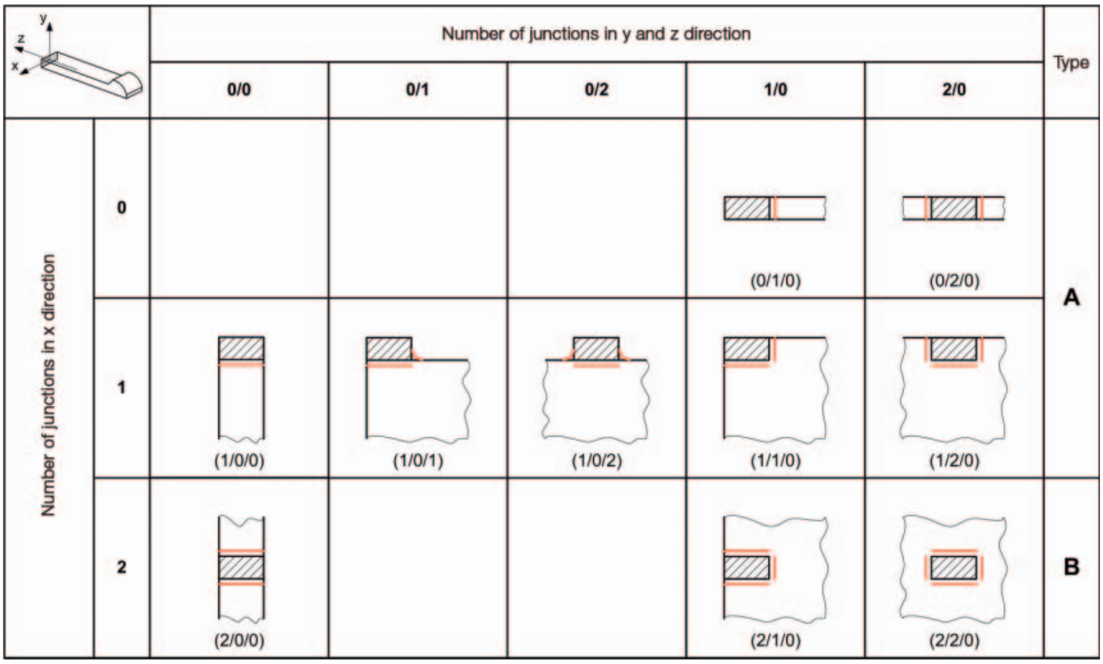

Fig. 1. Classification of junctions of snap-fit hooks

Two Basic Types of Junction

As a basis of the investigation a systematic classification of the possible forms of junction was elaborated. It is based on the number and orientation of the individual surface transitions from the flexing spring of the snap-fit hook to the plastic part in a Cartesian coordinate system. The x- and y-coordinates lie in the cross-sectional surface of the junction and the z-axis stands at right angles to this in the direction of the flexing spring (Fig. 1). The classification is limited to the most important variants that are more or less commonly encountered in practice and deliberately avoids inclusion of all theoretically conceivable possibilities.

The extensive investigations yielded the interesting conclusion that the junction variants considered could be assigned to two basic types A and B (Fig. 1). These differ essentially in the location of the maximum values of the stresses and strains occurring (Fig. 2).

Definition of Form Factors

The effects of a notch effect on stresses, strains and rigidity can be well described by so-called form factors α_k which, given linear-elastic material behavior, depend only on the geometry of the cross-sectional transition in question and of the molded part in question. These form factors are ratios between the maximum value of the physical variable in question during the notch effect and the corresponding nominal value in the absence of the notch effect. The most important geometric parameter is the ratio of the radius of curvature r to the cross-sectional height h (Fig. 3). When the form factors are known the maximum values can be calculated on the basis of the respective nominal values.

■ **Stress concentration factor:**

$$\alpha_{k\sigma} = \frac{\sigma_{\max}}{\sigma_n} = \frac{\sigma_{\max} \cdot W_b}{M_b} \quad (1)$$

■ **Strain concentration factor:**

$$\alpha_{k\varepsilon} = \frac{\varepsilon_{\max}}{\varepsilon_n} = \frac{\varepsilon_{\max} \cdot E \cdot W_b}{M_b} \quad (2)$$

■ **Stiffening factor:**

$$\alpha_{kf} = \frac{F_{eff}}{F_n} = \frac{F_{eff} \cdot l^3}{3 \cdot E \cdot I \cdot f} \quad (3)$$

The meaning of the symbols used in (1) to (3) is set out in a list (see box).

Symbols Used

F_{eff}:	Effective deflection force	[N]
F_n:	Theoretical deflection force	[N]
E:	Short-term modulus of elasticity	[N/mm^2]
M_b:	Bending moment in junction cross-section	[Nmm]
I:	Moment of inertia of the beam cross-section	[mm^4]
W_b:	Section modulus	[mm^3]
l:	Flexing length of snap-fit hook	[mm]
b:	Cross-section width of snap-fit hook	[mm]
h:	Cross-section height of snap-fit hook	[mm]
f:	Spring excursion, deflection of snap-fit hook	[mm]
r:	Radius at the junction	[mm]
$\alpha_{k\sigma}$:	Stress concentration factor	[–]
$\alpha_{k\varepsilon}$:	Strain concentration factor	[–]
α_{kf}:	Stiffening factor	[–]
ε_{max}:	Maximum strain	[–]
ε_n:	Nominal strain	[–]
σ_{max}:	Maximum stress	[N/mm^2]
σ_n:	Nominal stress	[N/mm^2]

Studies

The form factors were determined as a function of geometry by means of computational numeric investigations using the Finite Element Method (FEM). The programs MSC.Marc and ANSYS were used. The known stress concentration factor of a reduced flat bar under bending load [9, 10] was used as a reference for the serviceability of the models and the plausibility of the results.

A series of assumptions and idealised cases formed the basis of the study. These were:

- The flexing part of the snap-fit hook is of constant rectangular cross-section,
- The snap-fit hook consists of a plastic exhibiting linear-viscoelastic behavior, i.e. the time-dependent rigidity of the material described by the creep modulus is not a function of load,
- The rigidity of the material during a – short-term – joining or detaching operation is sufficiently well described by the modulus of elasticity E determined in short-term tests,

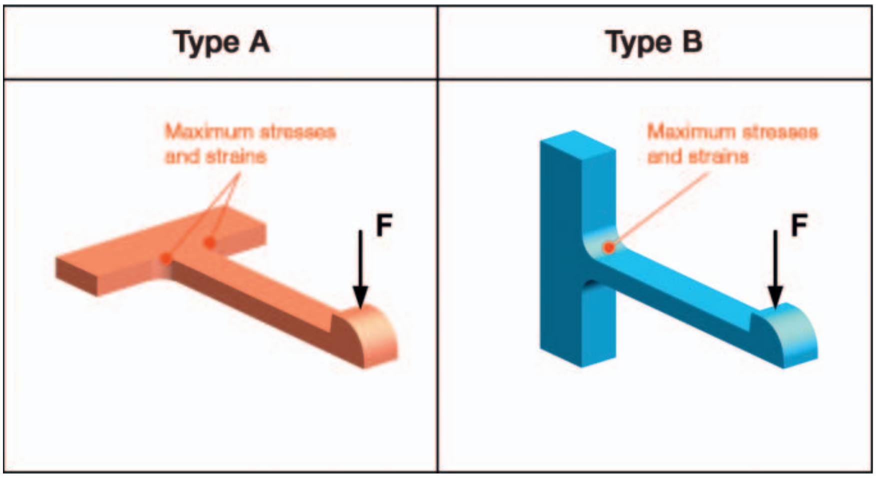

Fig. 2. Basic types A and B of snap-fit hook junctions

- The plastic part to which the snap-fit hook is attached exhibits comparatively high rigidity so that the deformation of the plastic part is negligible relative to that of the snap-fit hook,
- The mating part consists of a material of comparatively high rigidity so that as an approximating it can be modelled as a rigid body.

The geometric parameters were varied within the ranges $0.2 \le r/h \le 5$, $0.08 \le r/b \le 1$ and $10 \le l/h \le 50$. The formulas to be worked out for the form factors within these ranges were to be described in the simplest possible mathematical terms restricted to the decisive influences in operation.

The results of the studies confirm the allocation of the junction variants investigated to the two basic types A and B (Fig. 1) in accordance with the system of classification elaborated (Fig. 2), this applying throughout to the stress/strain concentration and stiffening factors.

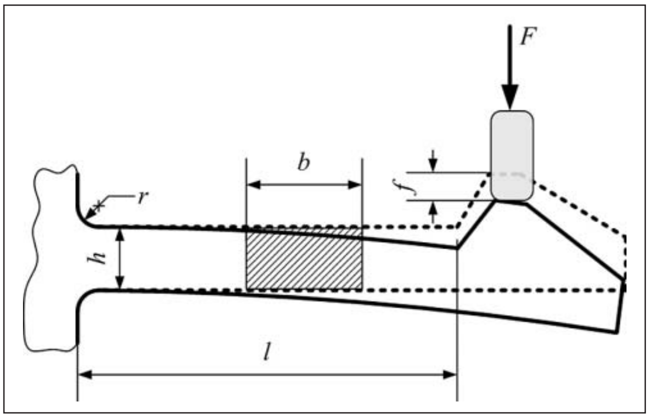

Fig. 3. Key geometric variables on a snap-fit hook

Stress Concentration Factor

On evaluating the stress concentration factor of junction type B as a function of the geometric parameter r/h a qualitatively similar pattern emerged from a cross-comparison with the reference values but with distinctly higher concentration factors (Fig. 4). The quantitative difference is explained by the effect of the ratio of the sides b/h of the rectangular cross-section. The reference values apply to reduced flat bars, that is to very small values of b/h. In contrast the snap-fit hooks studied fall into the range $1.7 \le b/h \le 8.7$. The greater this ratio becomes, the more transverse contraction is impeded, resulting in a stiffening effect and hence, for the same deflection, higher effective stress values. The relationship of the values obtained and the reference values fits this trend (Fig. 5). Accordingly, the results of the investigation can be considered as reliable and useful in practice.

The stress concentration factors obtained for junction types A and B are as expected primarily determined by the radius-dependent geometric parameter r/h (Fig. 6). In comparison with this the effects of the geometric parameters r/b and l/h and the number of Poisson's ratio proved to be insignificant [8] so that the hyperbolic curves can be represented to a good approximation by a power law and described by the relationships (4) and (5).

- **Stress concentration factor for junction A**

$$\alpha_{k\sigma} = 0.85 + 0.5 \cdot \left(\frac{r}{h}\right)^{-0.35} \tag{4}$$

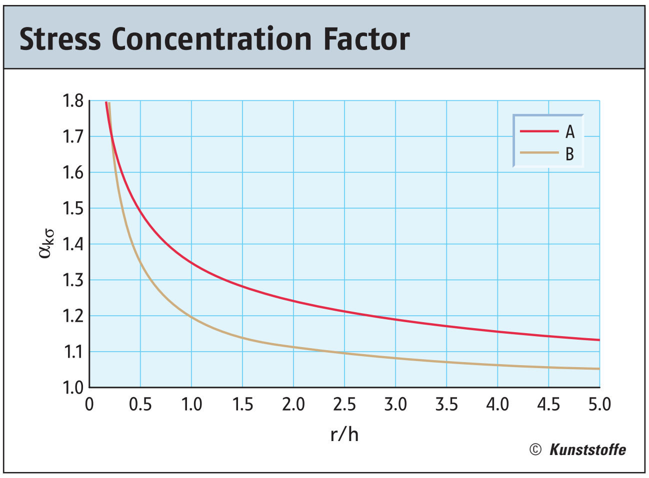

Fig. 4. Stress concentration factor as a function of the geometric parameter r/h: Cross-comparison with reference values

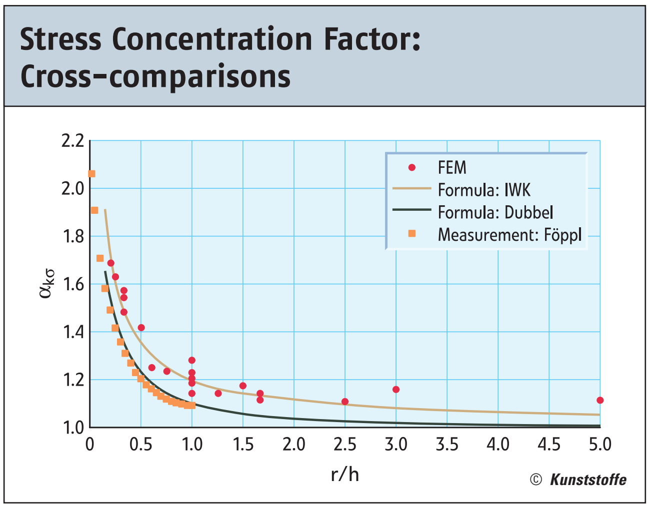

Fig. 5. Effect of cross-sectional width b on the stress concentration factor

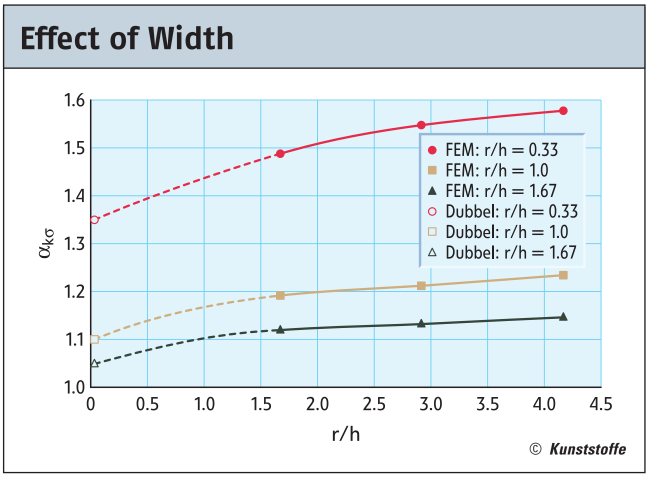

Fig. 6. Stress concentration factor as a function of the geometric parameter r/h

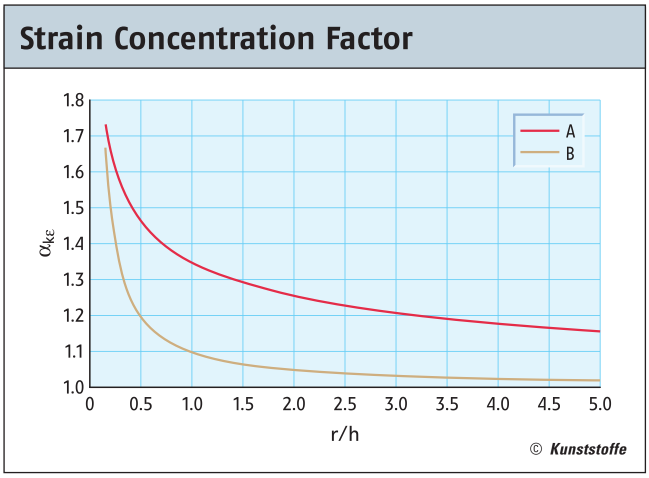

Fig. 7. Strain concentration factor as a function of the geometric parameter r/h

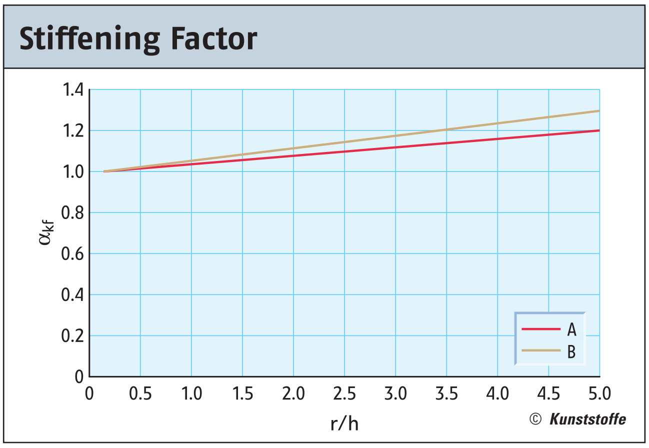

Fig. 8. Stiffening factor as a function of the geometric parameter r/h

Stress concentration factor for junction B

$$\alpha_{k\sigma} = 1.0 + 0.2 \cdot \left(\frac{r}{h}\right)^{-0.8} \tag{5}$$

These formulas replicate the results determined by FEM for all junction types with a standard deviation of 2.2 % for a mean deviation of 3.4 and 2.7 % respectively.

Strain Concentration Factor

Qualitatively the strain concentration factors run as a function of r/h (Fig. 7) like the stress concentration factors. Certain differences, however, are evident in the numerical values, in particular in the case of junction type B. These differences are due to the fact that in the region of the junctions, due to the geometry multiaxial stress states with corresponding impediments to deformation arise.

Strain concentration factor for junction A

$$\alpha_{k\varepsilon} = 0.85 + 0.5 \cdot \left(\frac{r}{h}\right)^{-0.3} \tag{6}$$

Strain concentration factor for junction B

$$\alpha_{k\varepsilon} = 1.0 + 0.1 \cdot \left(\frac{r}{h}\right)^{-1} \tag{7}$$

The mean deviation of the values from these formulas with respect to the results of the FEM calculations is 2.9 % and the standard deviation is 2.1 and 1.6 % respectively.

Stiffening Factor

The stiffening factor versus the geometric parameter r/h (Fig. 8) runs at a slightly upward inclination and shows an increase in rigidity of up to 10 to 20 %. The characteristic can be well described by a linear relationship resulting in the following formulas for the two junction types:

Stiffening factor for junction A

$$\alpha_{kf} = 1.0 + 0.04 \cdot \left(\frac{r}{h}\right) \tag{8}$$

Stiffening factor for junction B

$$\alpha_{kf} = 1.0 + 0.06 \cdot \left(\frac{r}{h}\right) \tag{9}$$

Formulas (8) and (9) match the numerically determined results with an accuracy of 3.7 % for the mean deviation and 2.7 % and 1.9 % respectively for the standard deviation.

Conclusion

As the order of magnitude of the form factors shows, the notch effect particularly with regard to stresses and strains must not be underestimated. It elevates the stresses and strains by 50 and more per cent in the range of r/h ratios common in practice. Accordingly, when setting limits for stresses or strains with respect to the corresponding permissible values the notch effect should be taken into account. In comparison with this the increase in stiffness as a result of rounding turns out to be distinctly lower. Accordingly, ignoring it when designing snap-fit hooks should be of little consequence.

The results presented have been determined on snap-fit hook models having a constant rectangular cross-section over the entire length of the flexing spring. In the case of snap-fit hooks whose cross-section tapers away from the junction the stress and strain concentration factors (4) to (7) can likewise be used at least in terms of an upper limit. The increase in stiffness as a result of rounding the junction is so low in such cases that it can be neglected.

If in a combined junction in the x and y directions of type B (Fig. 1) the radii are of different sizes it is recommended that both notch effects be checked by calculation. If the two radii are the same the ▶

notch effect at the junction predominates in the y direction. Although the tensile and compressive side of the linkage cross-section are in principle equally affected by the peaks in stress and strain, the tensile side, however, is critical on account of the mechanics of failure. This applies even for a twofold junction in the y direction with different radii. ■

ACKNOWLEDGEMENTS

The present paper was produced in the course of the research project: "Fundamentals of the Design of Plastic Structures". The authors thank the Gebert Rüf Stiftung, Basel, and the research fund of the HSR Hochschule für Technik Rapperswil for their support.

REFERENCES

1 Bonenberger, P. R.: The First Snap-Fit Handbook. Carl Hanser Verlag, Munich 2000

2 Tres, P. A.: Designing Plastic Parts for Assembly. 4th Ed., Carl Hanser Verlag, Munich 2000

3 N. N.: Feinwerkelemente – Schnappverbindungen. VDI/VDE-Richtlinie 2251, Sheet 7, 1998

4 N. N.: Berechnen von Schnappverbindungen mit Kunststoffteilen. Hoechst AG, Company brochure B.3.1, Frankfurt/Main 1991

5 N. N.: Schnappverbindungen aus Kunststoff. Praxisinformation Bayer AG. Company brochure KU 46040, Leverkusen 1988

6 Delpy, U.: Schnappverbindungen aus Kunststoff. expert Verlag, Ehningen bei Böblingen 1989

7 Lendi, M.: Untersuchungen zur Kerbwirkung bei Schnapphaken. Thesis, HSR Hochschule für Technik Rapperswil, 2004

8 Kunz, J., Studer, M., Lukic, D., Caduff, C.: Forschungsprojekt Auslegung von Schnappverbindungen. Miscellaneous internal unpublished documents. Research project, HSR Hochschule für Technik Rapperswil, 2005–2006

9 Grothe, K.-H., Feldhusen, J. (Eds.): Dubbel – Taschenbuch für den Maschinenbau. Springer Verlag Berlin, 21st edition, 2005

10 Föppl, L., Sonntag, G.: Tafeln und Tabellen zur Festigkeitslehre. Oldenbourg-Verlag, Munich 1951

THE AUTHORS

PROF. DIPL.-ING. JOHANNES KUNZ, born in 1940, Institut für Werkstofftechnik und Kunststoffverarbeitung (IWK; Institute of Materials Technology and Plastics Processing) at the HSR Hochschule für Technik Rapperswil, Switzerland; jkunz@hsr.ch

DIPL.-ING. MARIO STUDER, born in 1980, Scientific Associate at the IWK; mstuder@hsr.ch