
AL FOAMS / CELLULAR STRUCTURES: TECHNOLOGY AND PROPERTIES

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ABSTRACT

Cellular metallic materials and metallic foams are of practical interest due to their multifunctional characteristic combining properties such as good energy absorption, high hardness and low specific weight, which allow them for a high functional performance. The experimental processes and results on the fabrication of Al foam / cellular metal by the means of powder metallurgy are presented. In particular, powder metallurgy foaming method with TiH₂ blowing agent for closed cell foams production, with very low and gradual density, as well as samples characterisation, are described.

Tópico 6: Innovación

Keywords: powder metallurgy, aluminium, foams.

1. INTRODUCTION

Metallic foams can be described as an ensemble of cells with solid boundaries and faces connected between them [1], having combination of material and cellular structures properties [2]. The main quality of metallic foams is their multi functionality: good energy absorbers, low specific weight, thermal and/or sound isolation – reaching high performances that are often desired in the construction, automobile and aerospace industries [1,3,4]. Current research approaches a wide variety of themes: analysis on the foamed metal and evaluation of physical and mechanical properties [5-8].

In order to make technological applications involving metallic foams possible, the control and understanding of their mechanical properties needs to be realised. The mechanical properties are influenced by the structural properties of metallic foams which are determined by the parameters of the applied production process. It is commonly believed that properties of metallic foams are improved when the cells of the foam cells have uniform dimension and spherical shape, even though was not experimentally demonstrated. A clear influence of cell size and morphology on the process parameters has not been established yet; one of the main reasons for this is the lack of control over the parameters of the foaming process. Cells dimensions and wall shape have a great impact on the mechanical properties: the foams with wall defects have lower mechanical resistance than the foams of a more perfect structure[9]. Each stage of the production process can be influenced by many parameters and the final foams properties can vary if the production conditions are modified.

An important problem appears with the lack of a method to determine the quality of the foam. The uniformity of the cells is analysed on longitudinal and transversal sections. If the foams present cells with similar sizes, it is usually considered of good quality and if in the section presents

obvious defects is considered deficient. Problems, on the qualitative measurements, are given by morphological characteristics like broken walls that can pass unobserved.

Other problem encountered is the selection of the process parameters that need to be improved for the reason that is very difficult an exact replicate of the foams even on the same process parameters, being necessary a high number of samples for a valid conclusion.

2. EXPERIMENTAL PROCEDURE

The production process begins with the mixing of aluminium and alloy element powders (0.25% Cu, 0.6% Si, 1.0% Mg, Al-base) with the blowing agent, TiH₂ (0.8% and 1.6% wt.). Then the mixture is compacted to the shape of a solid cylinder referred to as a precursor. The preparation of the metallic precursor that will be foamed has an important influence on the final properties of the foam. The compaction to a high relative density (over 98%), was achieved using uniaxial compaction at 650 MPa, elastic die (500-700 MPa) and Cold Isostatic Pressing (C.I.P.) at 400 MPa, in which the blowing agent is embedded into the matrix without any notable residual open porosity. The precursor has to be manufactured very carefully because residual porosity or other defects will lead to poor results in further processing. The next step in the foaming process was heating at temperatures near the melting point of the metal matrix, i.e. in the range of 800-820°C. The blowing agent, which is homogeneously distributed within the dense metallic matrix, decomposes and the released gas forces the melting precursor material to expand, forming its highly porous structure. The time needed for full expansion was studied versus pressing, blowing agent contents and grain size of Al powder. The experimental condition for foaming stage was ensured by the computer control of temperature, recording the linear expansion of the precursor sample fixed at the bottom of a hollow mould from the furnace.

The metallic foams, developed from aluminium and aluminium alloy powder with titanium hydride were characterised: volume variation, cell morphology, micro and macro structure. Densities of the foamed samples according to experimental variables, compaction pressure, TiH₂ contents (0.4-1.2%) and metallic powder composition have been plotted. For the pore structure characterisation Micro Computed Tomography, optical and electronic microscopy analyses were used, respectively. Compression tests of the Al foam samples have also been made following the international standard for cellular materials (ASTM C-273-61).

3. RESULTS AND DISCUSSION

The foaming process is realised at the transition from solid phase of the material into liquid, being distinguished 4 stages on foam expansion, at 800°C, with decomposition of titanium hydride the physical support of the process. Time-expanded height curves presented in Figure 1 show a clear difference during foaming process in function of the foamed material (aluminium and 0.25%Cu, 0.6%Si, 1.0%Mg, Al-base).

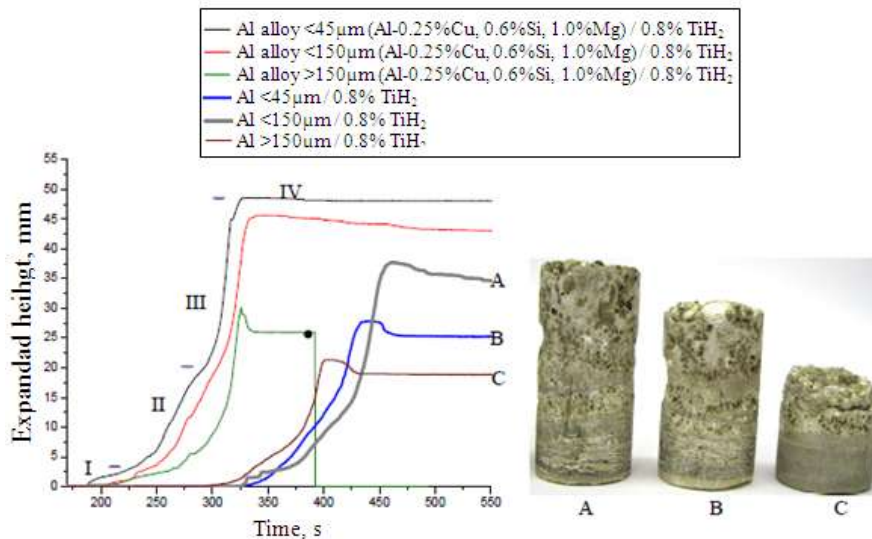


Figure 1. Influence of powder grain size on the foaming process of aluminium and aluminium alloy.

For each of the three powder grain sizes, individually analysed, the expansion is higher for small grain sizes (0-45 μm) and aluminium alloy; very low expansions were obtained for high grain sizes. It is clearly visible that the initial phase on foaming process, relatively low, followed by stages II and III, with much higher values of the expansion speed and the IV stage, considered the final of the process with evolution towards internal equilibrium.

For the precursors obtained by C.I.P. cold isostatic compaction (Figure 2), the expansion values reach 20 mm and 25 mm, respectively, for the precursor realized by classical compaction followed by Cold Isostatic Pressing. Density is not uniform, with high densities towards exterior; the expansion is produced, very late compared with the other samples, at 450 seconds and with reduced expansion values (25 mm); a high expansion speed is observed in the stage III (2,1 mm/s).

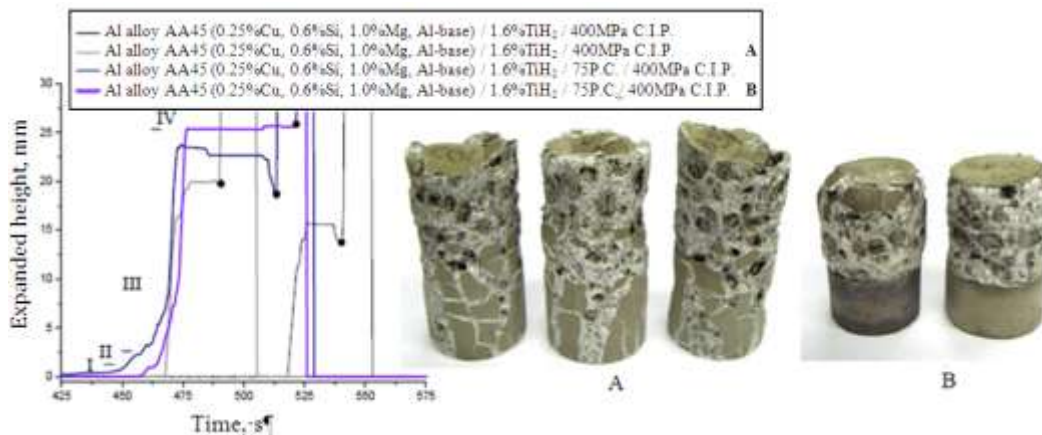


Figure 2. Expansion evolution and foams geometry obtained by C.I.P. (a), respectively classical compaction (75 MPa) followed by C.I.P. (b).

Foaming tests in function of compaction pressure-metal grain size-titanium hydride concentration show that at small grain size, for the same compaction pressure (600 MPa), the expansion is higher by increasing the titanium hydride content (Figure 3) from 28 mm at 38 mm. For the same concentration of TiH₂, pressure variation doesn't change the foaming curve evolution or the expansion height value. It is also observed that for high grain sizes, stage II, is realised with a lower

speed (0.06 mm/s), with very low expansion heights (12-16 mm), with no influence from compaction pressure and a positive influence on the expansion process is the small grain size of the foamed metal.

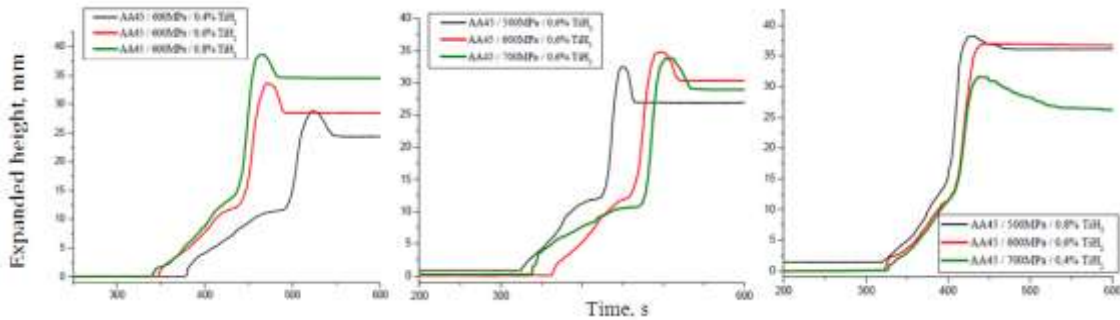


Figure 3. Foaming curves for Aluminium precursors realised by compaction in elastic die (500, 600, 700 MPa) with 0,4 / 0,6 / 0,8 % TiH₂

The physics of the foaming process by powder metallurgy with blowing agents makes possible to obtain closed-cells structures and gradual density. Photos realized with X rays (Figure 4) show a higher density on the inferior part of the sample. The density is higher in this part due to gravity which makes melted material to flow from the foam walls at the base of the sample.

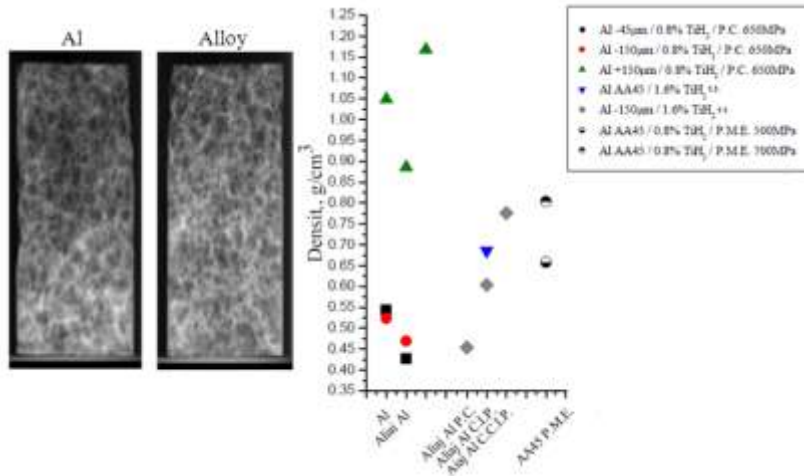


Figure 4. Density of the obtained foams

It can be observed that the small densities (the best ones) are obtained with aluminium alloy and small grain size. The grain size has a higher influence than compaction pressure, it can be seen that the highest densities were obtained with high grain size (>150 µm).

The analysis with micro Computed Tomography (Figure 5), by sectioning the sample in 400 plans gives detailed information on the foams entire volume.

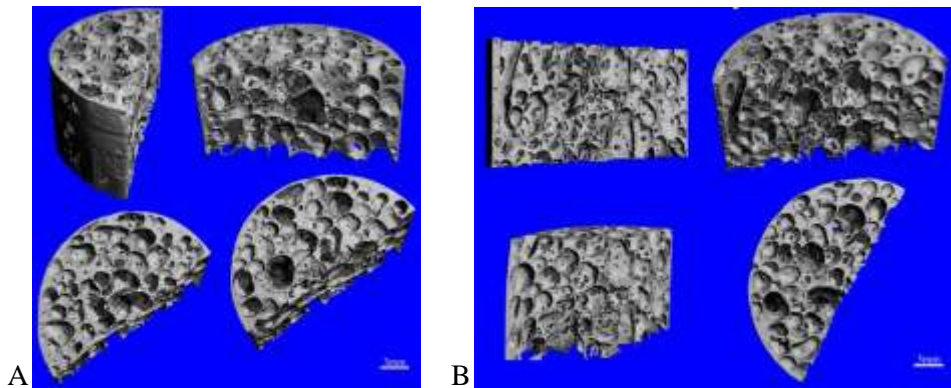


Figure 5. Scanned images with micro computed tomography of aluminium (A) and aluminium alloy (B) foams with 10-150 μm grain size and 0,8% TiH_2 , in longitudinal and transversal section plans.

For aluminium, the obtained values are z: 1.91 mm X : 0.98mm Y : 0.998 mm, the average cell wall size is 0,3654 mm and the average cell size is 1.8373 mm. For aluminium alloy the obtained values for anisotropy are X: 0.9210 mm Y: 0.9369 mm Z: 1.2214 mm, cell wall average size is 0.3825 mm and the average cell size is 1.7784 mm. It can be observed that the highest cells irregularity is in longitudinal section of the samples, anisotropy being more pronounced on z.

In the macro and micro structure of closed cells foams, the connections between cells or discontinuities of the cell walls are considered defects that are coming from the production method. The foams with the highest irregularities at macrostructure level are the foams obtained from high grain size and by C.I.P. (Figure 6).

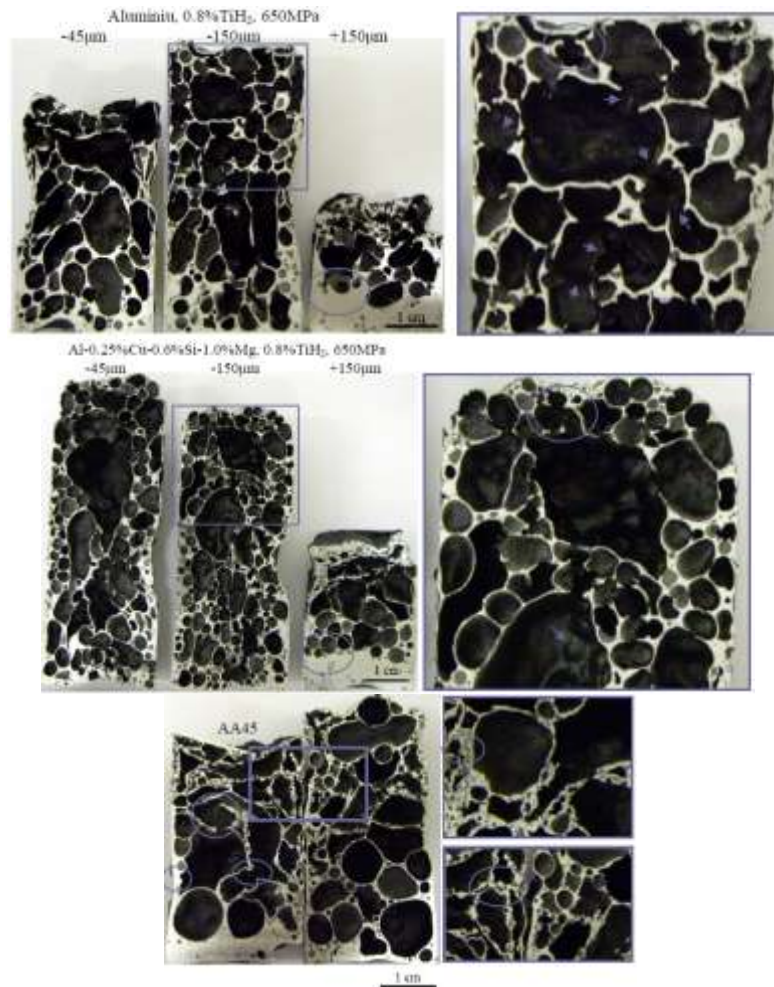


Figure 6. The macrostructure of the foams obtained with 0,8% and 1,6% TiH₂.

The defects in the cell sizes and shape also ruptures in the walls with variation of their size and shape can be observed in the foams obtained by classical compaction and elastic die.

The SEM images (Figure7), allow the characterisation and evolution of microstructure in correlation with the materials phase diagrams. By the interaction of titanium with melted aluminium, around titanium particles a layer of Al₃Ti is formed and no other intermetallic compound is observed.

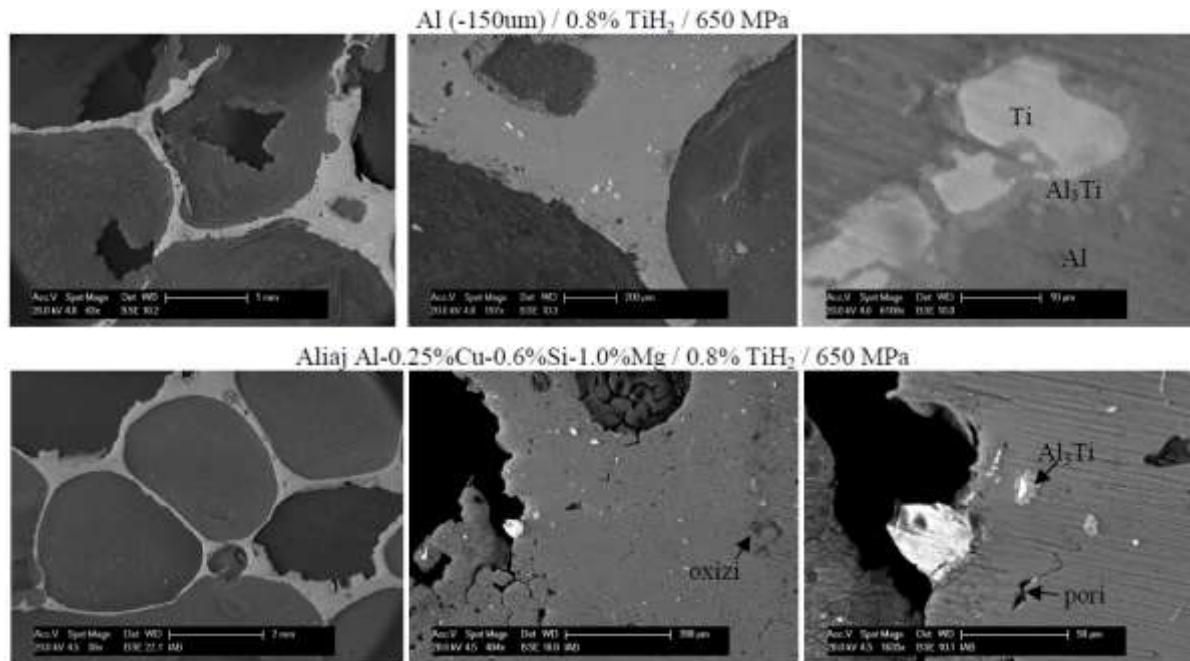


Figure 7. SEM images on the foam samples.

The macrostructure and the metal composition, besides density, have a high influence on the mechanical test. Compression uniaxial test of the foams is usually used to quantify the mechanic answer that these ones have in different regimes. The stress-strain curves (Figure 8) has a complicated shape, suggesting the incensement on tension with the incensement of deformation, specific for metal foams with closed cells, evolution that can be explained by the sustainment that the cell walls are giving on the tension actions, similar with the type of work of an elastic membrane. The compression resistance, considered the initial pick is relatively low, 3 MPa for aluminium alloy (Al-0,25% Cu-0,6% Si-1,0% Mg) and only 2 MPa for aluminium foams.

4. CONCLUSIONS

The conclusions that result from the experimental study are the following:

- the best densities were obtained with the aluminium alloy Al (-150 µm) 0.25% Cu-0.6% Si-1.00% Mg, precursor obtained by classical compaction;
- powder metal grain size has strong influence on the quality of the foams: small grain sizes will lead at good expansions and macrostructure;
- C.I.P. and classical compaction followed by C.I.P. have a negative influence on the expansion height, leading at low quality of the foams;
- anisotropy is higher on the height of the samples for both materials used (Al and Al alloy);
- the most homogenous density is observed by X ray analysis and macrostructure study of the foams obtained from aluminium alloy;
- for the same density, according to stress-strain diagrams, the energy absorbed is higher for the samples realized from aluminium alloy;
- a lower density makes possible the absorption of more energy.

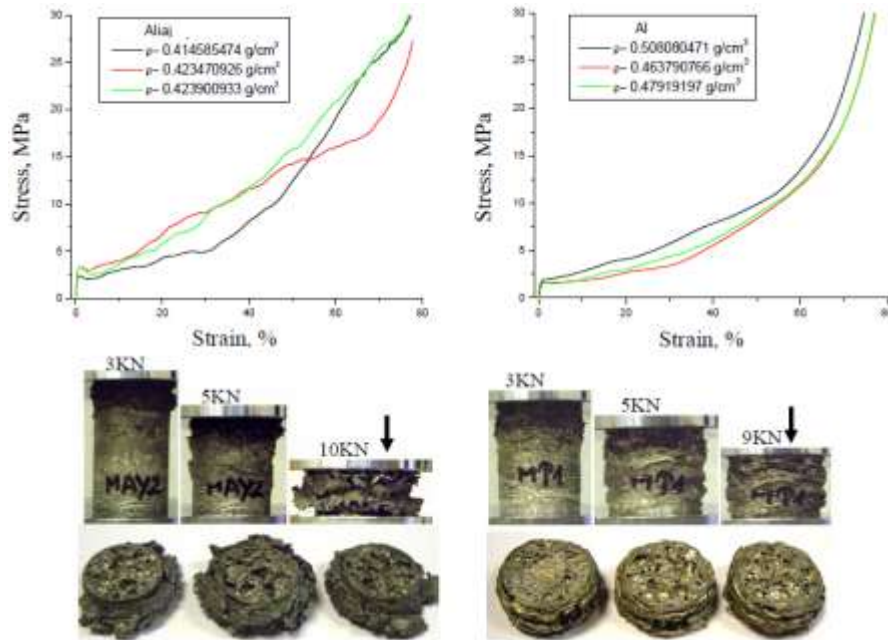


Figure 8. Aluminium alloy (Al-0.25%Cu-0.6%Si-1.0%Mg) (a) and aluminium (b) cu grain size 10-150 μm and 0.8% TiH_2 foams compression mechanical test.

REFERENCES

- [1] J. Banhart. "Manufacture, characterisation and application of cellular metals and metallic foams". *Progress in Material Science*, 46:559-632, 2001.
- [2] M.F. Ashby, A. Evans, N.A. Fleck, L.J. Gibson, J.W. Hutchinson, H.N.G. Wadley. "Metal foams - a design guide". Butterworth-Heinemann, London, 2000.
- [3] F. Baumgärtner, I. Duarte, J. Banhart. "Industrialisation of P/M foaming process". *Advanced Engineering Materials*, 2:168-174, 2000.
- [4] J. Banhart. "Aluminium foams for lighter vehicles". *International Journal of vehicle design*, 37:114-125, 2005.
- [5] A.H. Brothers, D.C. Dunand. "Amorphous metal foams". *Scripta Materialia* 54:513- 520, 2006.
- [6] M.D. Demetriou, G. Duan, C. Veazey, K. De Blauwe, W. L. Johnson. "Amorphous Fe-based metal foam". *Scripta Materialia* 57:9-12, 2007.
- [7] Z. Wanga, Z. Li, J. Ning, L. Zhao. "Effect of heat treatments on the crushing behaviour and energy absorbing performance of aluminium alloy foams". *Materials and Design* 30:977-982, 2009.
- [8] O. Gerbaux, F. Buyens, V.V. Mourzenko, A. Momponteil, A. Vabre, J.-F. Thovert, P.M. Adler. "Transport properties of real metallic foams". *Journal of Colloid and Interface Science* 342:155-165, 2010.
- [9] T. Daxner, HJ. Böhm, M. Seitzberger, FG. Rammerstorfer. "Modelling of cellular metals". In: H-P. Degischer, B. Kristz, editors. *Handbook of cellular metals*. Weinheim, Germany: Wiley-VCH; p. 245-80, 2002.