DETERMINATION OF STRAIN GRADIENT CHANGE INFLUENCE AT THE BORE EXPANSION TEST

SOBOTKA Jiří[1], SOLFRONK Pavel[1], KOLNEROVÁ Michaela[1], ZUZÁNEK Lukáš[1]

[1]TUL - Technical University of Liberec, Liberec, Czech Republic, EU
jiri.sobotka@tul.cz, pavel.solfronk@tul.cz, michaela.kolnerova@tul.cz, lukas.zuzanek@tul.cz

Abstract

The bore expansion test represents one of basic technological tests for determination preparation technologies influence on the maximal strain value. The most frequently it is used to determine material limit stage at comparison blanking and e.g. nonconventional cutting methods (abrasive water jet, laser and so on). Regarding the great development of contact-less optical methods for measuring deformation it is subsequently very suitable to use photogrammetry also at measurement and evaluation the bore expansion test. As an advantage there is e.g. very transparent graphical display of strain distribution around the bore without necessity to manually measure final bore diameter, information about strain change course during the whole test or also possibility to display strain gradient in any direction. On the other hand among disadvantages of contact-less optical deformation measurement is mainly purchase price, necessity of their precious adjustment before measurement (calibration of cameras, setting of shutters and so on) and also requirement for special surface treatment of sample (stochastic pattern). Within the experimental part of this paper there was measured the bore expansion test by contact-less optical system ARAMIS. As a tested material was chosen the phosphated deep-drawing material DC06. The purpose was to find out for six different initial diameters (from 5 mm up to 30 mm á 5 mm) strain distribution around bore for the last stage before the crack and subsequently to evaluate strain gradient change in radial direction. After that final data were processed statistically and graphically, mutually compared to determine strain gradient change influence.

Keywords: Bore Expansion Test, ARAMIS, Photogrammetry, Strain Gradient

1. INTRODUCTION

Processing of the sheets with coatings is very important part in the engineering industry (mainly in the automotive industry). One of the basic part of such whole processing technologies represents blanking which is very often carry out before the own pressing technology. Workpieces are cut not only at required shapes but there are also cut so-called technological holes. Surely these technologies influence materials plastic properties and sometimes there can occur cracks due to the achievement total ductility. That is why it is very important to know the deformation behavior of used material. The bore expansion test (see chapter 2) is one of the possible technological tests which can provide such type of information. Mostly it is used to determinate the influence of cutting clearance, however is this paper was investigated the rate of change for major strain $d\varphi_1$ [mm^{-1}] influence on the initial diameter of the hole. Thus there was carried out this test for different initial diameters of holes and from the data for major strain φ_1 [1] distribution in the radial direction to the edge were computed these rates of change via differentiation with the respect to the length of used section L [mm]. Finally from these dependences it was possible to make some conclusions about influence of the initial geometry of hole on the material plastic properties. So in this case was determined strain gradient change (rate of change) of different initial diameters to see not only distribution of major strain φ_1 [1] around these holes but mainly to see the rate of change for major strain $d\varphi_1$ [mm^{-1}] - thus to know the slope of these curves in the radial directions to the edge of the used material.

2. METHODOLOGICAL BASE AND EXPERIMENTAL PART

As a main experimental test for this paper it was used so-called the bore expansion test which is sometimes named as Siebel and Pomp test. [1] The principle of such test is shown in Fig. 1. The tested material is placed between blank holder and die and is subsequently formed by flat punch up to the moment of crack creation. After that can be measured final diameter and values of major strain φ_1 [1] can be computed. This test can have many applications as can be e.g. determination the influence of cutting clearance. In this paper was determined the influence of initial bore diameters (see Table 2) on the distribution of major strain φ_1 [1]. As a tested material it was used the phosphate deep-drawing material which is commonly marked as DC05+ZE75/75-BPO. Its mechanical properties are summarized in Table 1.

Table 1 Mechanical properties of the tested material (DC05+ZE75/75-BPO)

Rolling direction / Mechanical properties	Yield strength $R_{p0,2}$ [MPa]	Ultimate strength R_m [MPa]	Uniform ductility A_g [%]	Total ductility A_{80mm} [%]
Rolling direction 0°	174.5	298.1	24.36	43.71
Rolling direction 45°	182.2	303.8	21.86	38.71
Rolling direction 90°	175.3	292.1	22.86	41,85

Table 2 Used initial diameters for the bore expansion test and their abbreviations

Initial diameter / Its abbreviation	D5	D10	D15	D20	D25	D32
Initial diameter ØD [mm]	5	10	15	20	25	32

The whole procedure, evolution and evaluation of the bore expansion test (see Fig. 1) was carried out by the contact-less optical system ARAMIS which uses photogrammetry to compute deformation. Thus before the own measurement there was very important to precisely calibrate and focus cameras, adjust lights and set proper distances (all of that because of photogrammetry and ARAMIS system). On the next page are shown images from such measurement and distribution of major strain φ_1 [1] right before the crack creation.

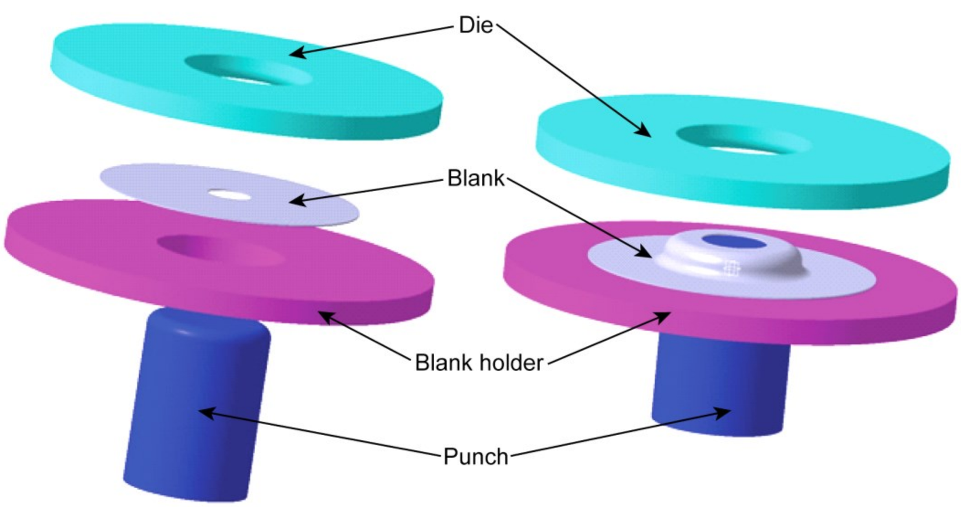

Fig. 1 Principle of the bore expansion test

The whole bore expansion test was scanned by the contact-less optical system ARAMIS and distribution of major strain φ_1 [1] was computed. Such distributions for initial diameters 5 mm and 32 mm and moment right before the crack creation (there was used 6 fps so it is 0.167 sec before the crack) are shown in Fig. 2.

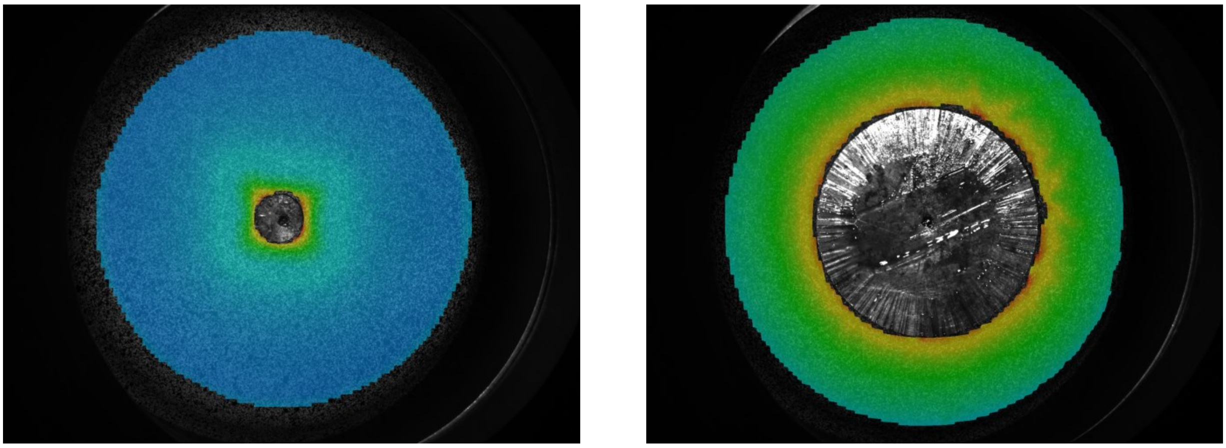

Fig. 2 Distribution of major strain φ_1 [1] for D5 (left) and D32 (right) - moment right before the crack creation

By the contact-less optical system ARAMIS there were measured all tested diameters and stages right before the crack were selected. From all available results at these stages was the crucial distribution of major strain φ_1 [1] as it is shown in Fig. 3 for D5. There is also possible to see the position and radial direction of used section 1 [mm] along that was subsequently determined the required rate of change for major strain $d\varphi_1$ [mm^{-1}]. From this Fig. 3 is also evident probably the biggest disadvantage arising from using cameras for measurement the bore expansion test. Such disadvantage reflects reality that as optical system computes strain via co-called facets [px], there is no possibility to achieve just edge of the bore. Thus there is always a small "gap" between this edge and first computed values of strain. It is only possible to lower that distance by using smaller and smaller facets (in this paper was used 7 x 7 px).

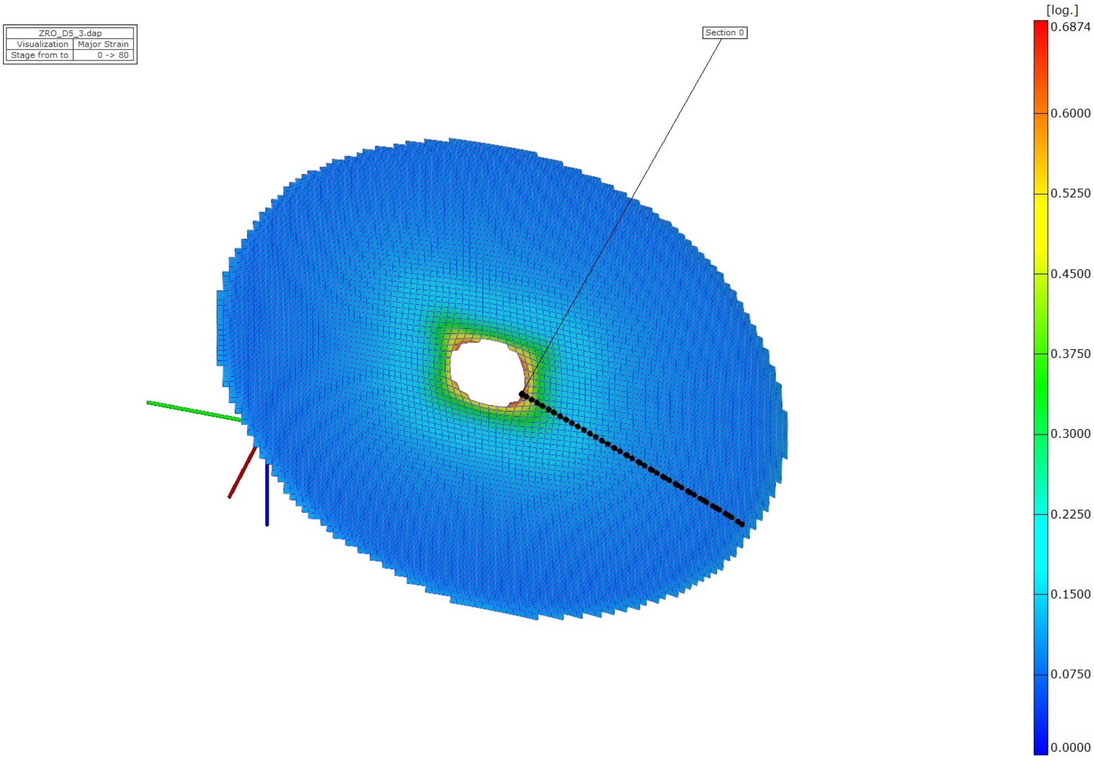

Fig. 3 Distribution of major strain φ_1 [1] for D5 - moment right before the crack creation (system ARAMIS)

In Fig. 4 are shown results from measurement major strain φ_1 [1] distribution for D5 along sections. For every diameter there were used three samples from those was finally computed average curve (as average from multiple curves). That final average curve is in Fig. 4 shown in red color.

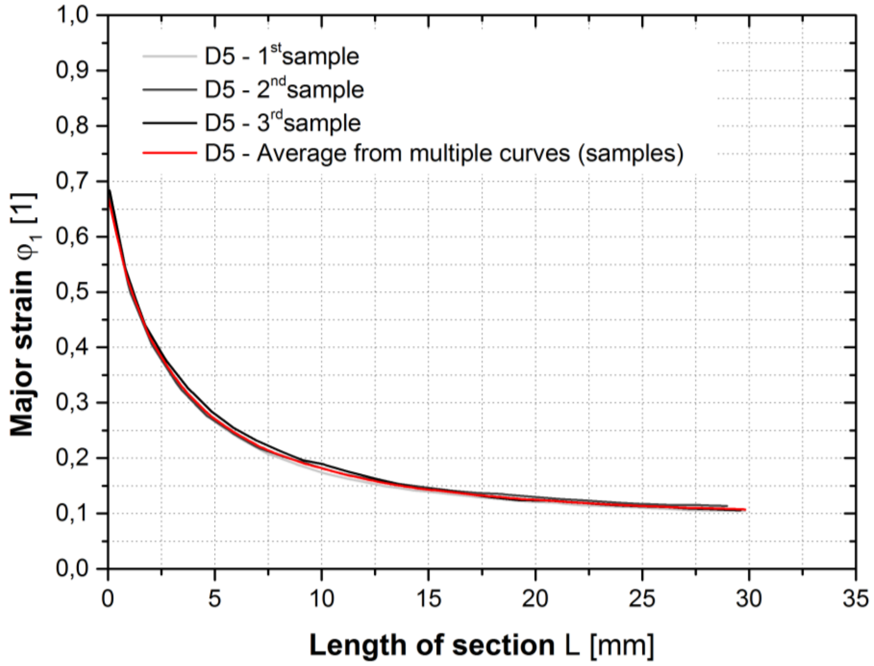

Fig. 4 Major strain φ_1 [1] distribution for D5 - average curve from multiple curves (red color)

After determination of these average curves for every used diameter (D5, D10, D15, D20, D25 and D32) there followed probably the crucial processing of these data via their differentiation with respect to length of section L [mm] to be able to compute rate of change for major strain $d\varphi_1$ [mm^{-1}]. In Fig. 5 are shown results from this differentiation for diameter D5. On the left is shown "raw" result from differentiation with respect to length of section L [mm]. It is evident that such data processing is very sensitive and that is why there was necessary to add one more data processing method which rested in smoothing of measured curve. In this case there was used just B-spline (basis spline) of 1st differentiation. [2, 3] Comparison of "raw" data from differentiation (red color) and its B-spline (black color) is shown in Fig. 5 on the right. Such smoothing method was subsequently used for every measured diameter. Cause the major interest in this paper was focused just on the first part of these final curves are in Fig. 6 shown these curves (still D5) just for 10 mm.

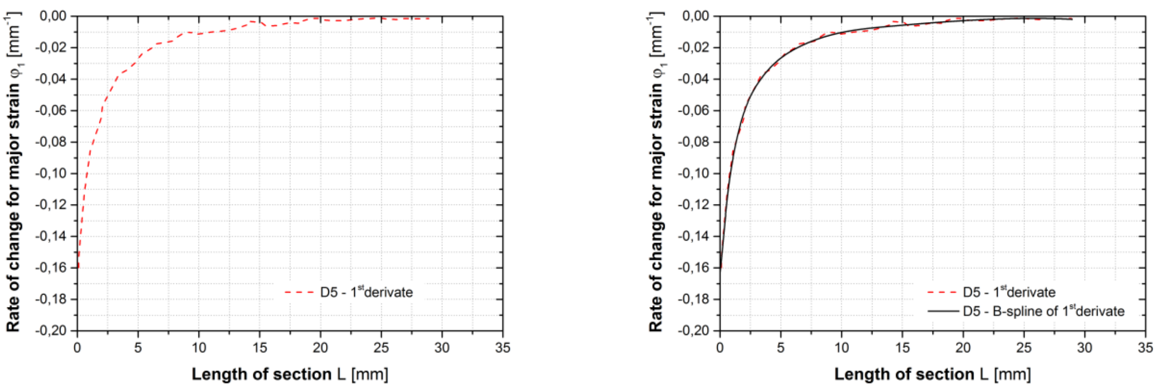

Fig. 5 Differentiation (left) and B-spline (right) for D5

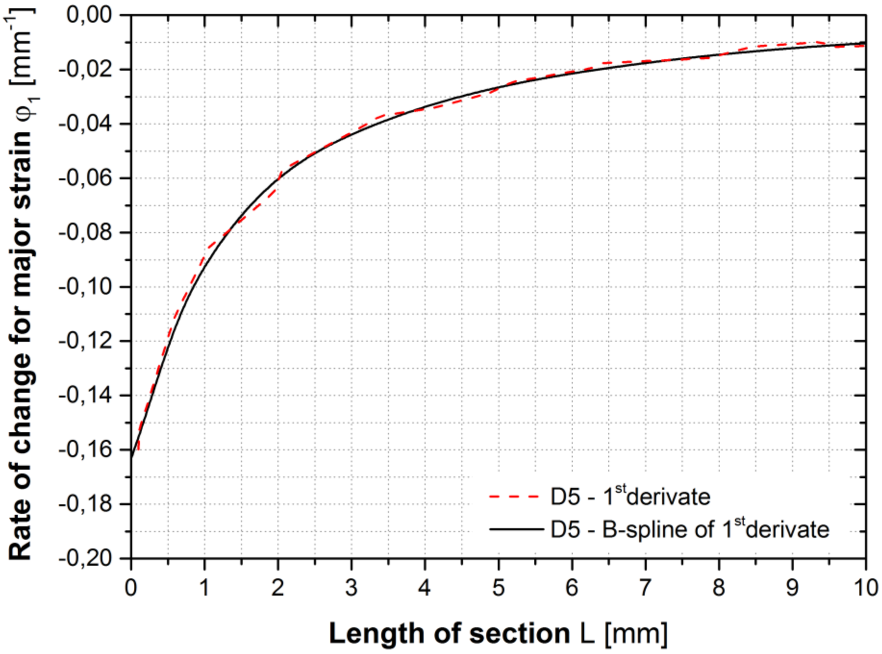

Fig. 6 Differentiation and B-spline for D5 - detail for the first 10 mm

Finally in Fig. 7 are subsequently summarized final rates of change for major strain $d\varphi_1$ [mm^{-1}]. From Fig. 7 is evident the influence of initial diameter on the rate of change for major strain $d\varphi_1$ [mm^{-1}]. Such influence can be thus summarized as following: the higher initial diameter, the lower rate of change $d\varphi_1$ [mm^{-1}]. In other words: the lower initial diameter, the lower material plastic properties depletion from the edge of bore. [4]

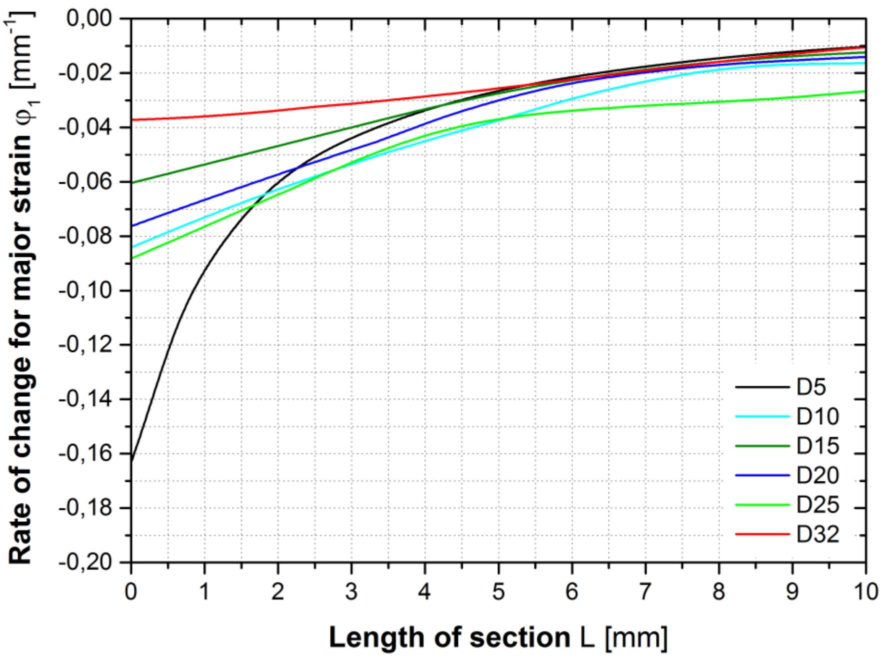

Fig. 7 Rate of change for major strain $d\varphi_1$ [mm^{-1}] - all used initial diameters

CONCLUSION

This paper deals with the determination rate of change for major strain φ_1 [mm^{-1}] in dependence on initial diameters (D5, D10, D15, D20, D25 and D32) by means of the bore expansion test. As a tested material it was used phosphate deep-drawing material DC05 and for computation of major strain φ_1 [1] distribution was used contact-less optical system ARAMIS. In Fig. 7 are shown rates of change for major strain $d\varphi_1$ [mm^{-1}] as a main result from the experimental part and in Fig. 8 are shown just major strains φ_1 [1] distributions along sections as data which were subsequently differentiated. From these two the most important results it is evident that the higher initial diameter, the lower rate of change $d\varphi_1$ [mm^{-1}] and thus the lower material plastic properties utilization from the edge of bore. Such type of information about material deformation behavior is very important e.g. in the press shops in the case of so-called technological holes because there is danger of depletion material plastic properties. It is evident that the lower initial diameter of the hole, the much faster localization of deformation, necking (as during the static tensile test) and the crack creation. That was also the main purpose of this paper which deals with the influence of initial diameter of the hole (thus generally geometry) on the material plastic properties. On the other hand this experimental represents just first results and it is very important to carry out much more tests, to test different materials and so on. Very important is also smoothing of differentiated data cause such computation is very sensitive to every peak and valley. Moreover there are some disadvantages arising from usage of photogrammetry mentioned above.

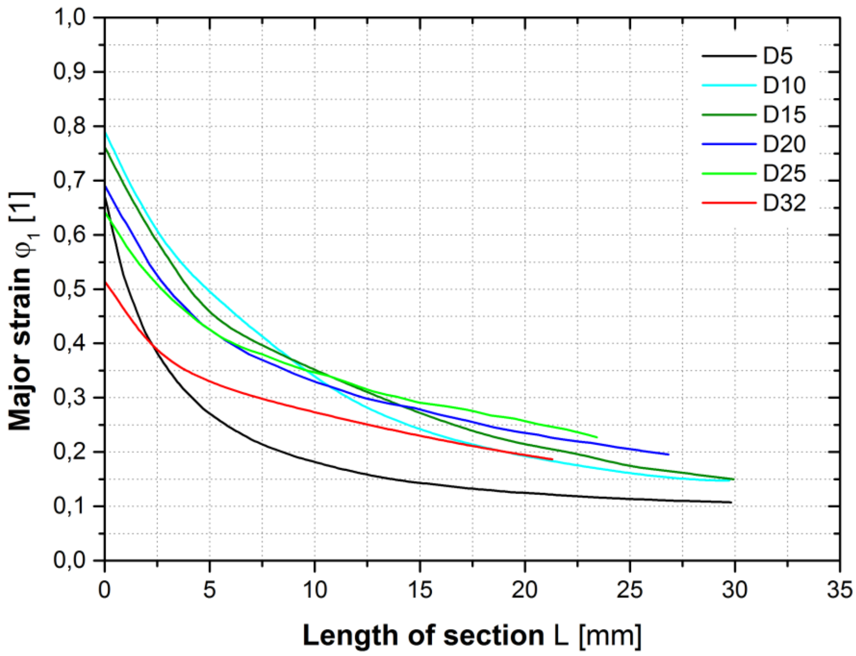

Fig. 8 Major strain φ_1 [1] distributions - all used initial diameters

REFERENCES

[1] ASM HANDBOOK. Volume 14B – Metalworking: Sheet Forming. 2nd ed. Materials Park: ASM International, 2006.

[2] HOSFORD, W.F., CADDEL, R. Metal Forming (Mechanics and Metallurgy). 3rd ed. New York: Cambridge University Press, 2007.

[3] HERTZBERG, R.W. Deformation and Fracture Mechanics of Engineering Materials. 4th ed. New York: John Wiley & Sons, 1996.

[4] DAVIES, G. Materials for Automobile Bodies. Oxford: Butterworth-Heinemann, 2003.