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PUNCH FORCE OPTIMIZATION IN THE DEEP DRAWING OF AA 6061 SHEET MATERIAL

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ABSTRACT

Deep drawing is one of the fundamental sheet forming operations that has complicated deformation mechanisms. Fundamental understanding of variation of the parameters that affect the process has become essential for accurate rapid design of tooling and processes in early design stage. The punch force needed for deep drawing is one of the important factors as this force is a resultant of the forces needed to bend, straighten, compress and overcome friction. These forces are significantly influenced by the parameters such as die shoulder radius, punch nose radius and blank holder force. Smaller punch force is desired for successful drawing process. And also prediction of forming load is necessary to select the suitable forming machine. Therefore, in this paper, the effect of such parameters on the punch force needed in deep drawing of AA 6061 sheet material has been investigated and the parameters have been optimized for minimum punch force.

KEYWORDS: Deep Drawing, AA 6061, Optimization, Response Surface Methodology, Punch Force

INTRODUCTION

Sheet metal forming is a significant manufacturing process for producing large variety of automotive parts and aerospace parts as well as consumer products. Deformation of sheet materials in the stamping process is classified by the four deformation modes. They are deep drawing, stretching and stretch flanging and bending [1]. Deep drawing is one of the widely used sheet metal forming processes in the industries, to produce cup shaped components at a very high rate. Cup drawing, besides its importance as forming process, also serves as a basic test for the sheet metal formability. During the course of deep drawing process the following five processes take place [2]. i. Pure radial drawing between the die and blank holder, ii. Bending and sliding over the die profile, iii. Stretching between the die and the punch, iv. Bending and sliding over the punch profile radius, and v. Stretching and sliding over the punch nose. Thus the deep drawing process involves complex deformation mechanisms. The equipment and tooling parameters that affect the success or failure of a deep drawing operation are the punch and die radii, the punch and die clearance, the press speed, the lubrication and the type of restraint to metal flow in deep-drawn shapes. Among these the die shoulder radius [3-6] punch nose radius [3-5] and the blank holder force [4-8] are considered to be significant parameters in the deep-drawing process. In the flange zone and die shoulder radius, the strain energy and frictional resistance are the major sources of energy consumption. The force transmitted to the wall mainly depends on the strain energy spent for deformation at the flange region and die radius. The bending effects also have considerable influence on the energy dissipation [11]. The bending effects are mainly influenced by the above said parameters. The punch force needed for deep drawing is one of the important factors as this force is a resultant of the forces needed to bend, straighten, compress and overcome friction. These forces are significantly influenced by die shoulder radius, punch nose radius and blank holder force. A smaller punch force would predict drawing success. The lowest punch force is desired because the higher is the punch force the greater is the amount of wear on the tooling, which is critical in industry where expensive tooling for complicated components cannot be replaced on a regular basis [15]. And also determination of forming load is helpful in selecting the suitable presses for the deep drawing operation. In this work an attempt has been made to study the influence of these parameters on punch force in deep drawing of AA 6061 sheet material and to optimize the parameters to attain minimum punch force using Response Surface Methodology.

EXPERIMENTATION

Drawing Tools

Fundamental understanding of the variation of the parameters has become essential for accurate and rapid design of tooling and processes in early design stage. In deep drawing, the quality of the formed parts is affected by the amount of the metal drawn into the die cavity. Excessive metal flow will cause wrinkles in the part while insufficient metal flow will result in tears or splits. Figure 1 shows the schematic view of the deep drawing process. It has been shown that for a punch nose radius (PR) that is less than twice the thickness of the blank (t), the cup fails due to tearing, whilst for PR greater than 10t, stretching may be introduced. In addition, within region $4t < PR < 10t$, the radius does not significantly affect the limiting draw ratio (LDR) [2]. Therefore according to the thickness of the blank, the most suitable shoulder radii for the die and punches were found to be in the range of 3 to 8 mm with a constant punch stem diameter of 100 mm and a die cavity of 102.5 mm [9, 16]. Proper tool steel with appropriate mechanical properties and hardening treatment was used for the materials for the punches and dies. The tools were ground to finish and final hardness of 64 HRC. The amount of blank holder force required to prevent wrinkles is largely determined by trail and error. The pressure required to hold a blank flat for a cylindrical draw vary from very little to a maximum about one third of the drawing pressure [10]. Therefore the maximum blank holder force was theoretically arrived to be 10kN. And experimentally, it was found that a blank holder force of less than 4 kN results in wrinkles. The punch nose radius (PR), die shoulder radius (DR) and blank holder force (BHF) were considered to be the predominant parameters in the deep drawing process. The parameters selected were varied with three levels. Table 1 exhibits the different levels of the chosen parameters.

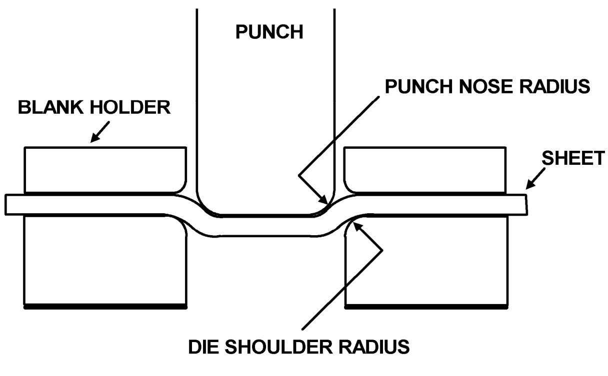

Figure 1: Schematic of the Deep Drawing Process

Table 1: Parameters and their Levels

Parameter	Symbol	Levels		
		-1	0	1
Punch nose radius, mm	PR	3	5.5	8
Die shoulder radius, mm	DR	3	5.5	8
Blank holder force, kN	BHF	4	7	10

Response Surface Methodology (RSM)

The RSM is an empirical modeling approach for determining the relationship between various parameters and responses with the various desired criteria and search in the significance of these process parameters on the coupled responses [12]. It is a sequential experimentation strategy for building and optimizing the empirical model. Response surface methodology is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response [13]. Through the design of experiments and applying regression analysis the modeling of the desiring response to several independent input variables can be gained. In many experimental conditions, it is possible to represent independent factors in quantitative form as given in Eq.(1). Then these factors can be thought of as having a functional relationship or response as follows:

$$y = f\,(x_1, x_{2,}\, x_3 ....x_n\,) \pm \varepsilon \qquad (1)$$

Where y is the desired response, f the response function (or response surface), $x_{1,}$ x_2, x_3……,x_n are the independent input variables, and ε is the fitting error. The appearance of the response function is a surface as plotting the expected response of *f*. The identification of suitable approximation of *f* will determine whether the application of RSM *is* successful or not. In this study the approximation of *f* will be proposed using the fitted second order polynomial regression model, which is called the quadratic model. The quadratic model of *f* can be written as follows,

$$f = a_o + \sum_{i=1}^{n} a_i x_i + \sum_{i=1}^{n} a_{ii} x_i^{\;2} + \sum_{j>i}^{n} a_{ij} x_i x_j + \varepsilon \qquad (2)$$

where a_i represents the linear effect of x_i, a_{ii} represents the quadratic effect of x_i and a_{ij} reveals the linear-by-linear interaction between x_i and x_{ij}. The response surface *f* contains the linear terms, squared terms and cross product terms. Using this quadratic model of *f* in this study is not only to investigate over the entire factor space, but also to locate region of desired target where the response approaches is optimum or near optimal value. In this study the experimentation scheme was designed in such a way as to explore the influence of the various predominant parameters (The punch nose radius (PR), die shoulder radius (DR) and blank holder force (BHF)), based on Response surface methodology in order not only to obtain the optimum scheme for multivariable experimentation, but also to perform studies for exploring the interactive and higher order effects of the various parameters considered. In order to estimate the regression coefficients, central composite face centered design was used which fits the second order response surfaces very accurately. Central composite face centered (CCF) design matrix with the star points being at the center of each face of factorial space was used, so α= ±1. This variety requires three levels of each factor. CCF designs provide relatively high quality predictions over the entire design space and do not require using points outside the original factor range. The upper limit of a factor was coded as +1, and the lower limit was coded as –1. All the coefficients were obtained applying central composite face centered design. Table 2 shows the design matrix with coded and actual values.

Experimentation

The punches and dies were fabricated with shoulder radii 3, 5.5 and 8 mm (as shown in Table 1) with a constant punch stem diameter of 100 mm and a die cavity of 102.5 mm [9]. The deep drawing machine that was used in investigation was a double action hydraulic press with a maximum load capacity of 150 tons. The lubricant used was a commercially available Mineral oil [14]. The material used in the present study is the commercially available AA 6061 Aluminum alloy sheet which has wide acceptance in automobile and aerospace applications. The thickness of the sheet is 0.8 mm. The mechanical properties of the material were determined using tensile test and are given in Table 3.The experimental setup is shown in Figure 2. Twenty experimental runs were conducted according to the designed scheme. Figure 3 shows the cups drawn for each experimental run.

Table 2: Design Matrix in Actual and Coded Values

Exp. Run	Coded Value			Actual Value			Punch Force kN
	PR	DR	BHF	PR	DR	BHF	
1	-1	1	1	3	8	10	26
2	0	0	0	5.5	5.5	7	20
3	0	-1	0	5.5	3	7	23
4	0	1	0	5.5	8	7	21
5	0	0	1	5.5	5.5	10	23
6	0	0	0	5.5	5.5	7	21
7	0	0	0	5.5	5.5	7	21
8	1	1	1	8	8	10	24
9	1	1	-1	8	8	4	17
10	1	-1	-1	8	3	4	20
11	1	-1	1	8	3	10	25
12	0	0	0	5.5	5.5	7	21
13	-1	-1	1	3	3	10	29
14	-1	0	0	3	5.5	7	22
15	-1	1	-1	3	8	4	16
16	0	0	0	5.5	5.5	7	20
17	0	0	-1	5.5	5.5	4	15
18	-1	-1	-1	3	3	4	22
19	1	0	0	8	5.5	7	23
20	0	0	0	5.5	5.5	7	21

Table 3: Uniaxial Tensile Test Data for AA 6061 Al Alloy Sheet

Ultimate Tensile Strength	208 MPa
Tensile Yield Strength	107 Mpa
Elongation (%)	18

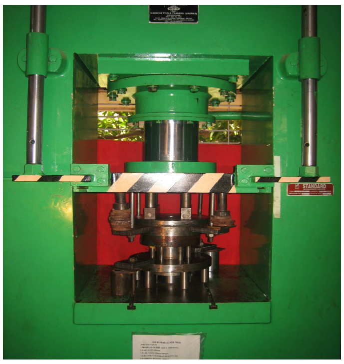

Figure 2: Photograph of the Experimental Setup

Figure 3: Photograph of the Drawn Cups

RESULTS AND DISCUSSIONS

Mathematical Modeling of Punch Force

The maximum punch force was measured for each experimental run and is given in Table 2. Using the experimental results, the regression model equation (second order polynomial) relating to the effects of the parameters on the magnitude of the punch force was developed and is given in Eq.4.4. The significance of parameters and the coefficient of each term are given in Table 4.8.

$$\text{Punch Force} = 27.0464 - 3.5667PR - 4.2133DR + 3.7081BHF + 0.3055PR^2$$
$$+ 0.2255DR^2 - 0.1768BHF^2 + 0.1000PR*DR$$
$$- 0.0833PR*BHF + 0.0833DR*BHF \quad (4.4)$$

In order to ensure the goodness of fit of the quadratic model in this study, the test for significance of the regression model, the test for significance on individual model coefficients and test for lack of fit need to be performed [12]. Analysis of variance is usually applied to summarize the above tests. ANOVA is a statistical technique that subdivides the total variation in a set of data into component parts associated with specific sources of variation for the purpose of testing hypothesis on the parameters of the model. From Table 5, The P value for the regression model is lower than 0.05 ($\alpha = 0.05$, or 95% confidence) which indicates that the model is considered to be statistically significant. It demonstrates that the terms in the model have significant effect on the response.

Table 5: ANOVA Table for the Quadratic Model of Punch Force

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	197.648	197.648	21.9609	41.03	0.000
Linear	3	163.000	32.394	10.7979	20.17	0.000
PR	1	3.600	9.436	9.4364	17.63	0.002
DR	1	22.500	13.168	13.1684	24.60	0.001
BHF	1	136.900	13.408	13.4084	25.05	0.001
Square	3	25.273	25.273	8.4242	15.74	0.000
PR*PR	1	16.200	10.023	10.0227	18.73	0.001
DR*DR	1	2.113	5.460	5.4602	10.20	0.010
BHF*BHF	1	6.960	6.960	6.9602	13.00	0.005
Interaction	3	9.375	9.375	3.1250	5.84	0.014
PR*DR	1	3.125	3.125	3.1250	5.84	0.036
PR*BHF	1	3.125	3.125	3.1250	5.84	0.036
DR*BHF	1	3.125	3.125	3.1250	5.84	0.036
Residual Error	10	5.352	5.352	0.5352		
Lack-of-Fit	5	4.019	4.019	0.8038	3.01	0.126
Pure Error	5	1.333	1.333	0.2667		
Total	**19**	**203.000**				

Table 6: ANOVA Table for the Significance of the Parameters

Term	*Coef*	*T*	*P*
Constant	27.0464	9.013	0
PR	-3.5667	-4.199	0.002
DR	-4.2133	-4.96	0.001
BHF	3.7081	5.005	0.001
PR*PR	0.3055	4.327	0.001
DR*DR	0.2255	3.194	0.01
BHF*BHF	-0.1768	-3.606	0.005
PR*DR	0.1	2.416	0.036
PR*BHF	-0.0833	-2.416	0.036
DR*BHF	0.0833	2.416	0.036

The other important coefficient R^2 in the resulting ANOVA is defined as the ratio of the explained variation to the total variation and is the measure of the degree of fit. When the R^2 approaches unity, the better the response fits the actual data. The calculated value of R^2 for this model is over 0.95 (97.36%), reasonably close to unity, which is acceptable. It indicates that about 95% of the variability in the data is explained by the model. The adjusted R^2 is 94.99%, which indicates that the quadratic model is adequate to represent the variability of the punch force as a function of the selected parameters. The lack of fit is significant as desired.

Effect of Die Shoulder Radius and Blank Holder Force on Punch Force

Figure 4 shows the estimated response surface for die shoulder radius and blank holder force on punch force. For any value of blank holder force in the specified limits the punch force gradually decreases with increase in die shoulder radius. When die shoulder radius increases, the material passes over a generous bend. As a result of which the resistance to the flow of material decreases which in turn decreases the force required to draw. As the blank holder force is increased the material is held tightly between the blank holder and the die face. Higher value of force is required for drawing to overcome the higher clamping force. The increase in blank holder force increases the punch force consistently. And also it is noted that the punch force requirement is maximum when the die shoulder radius is minimum (3 mm) and blank holder force is maximum (10 kN).

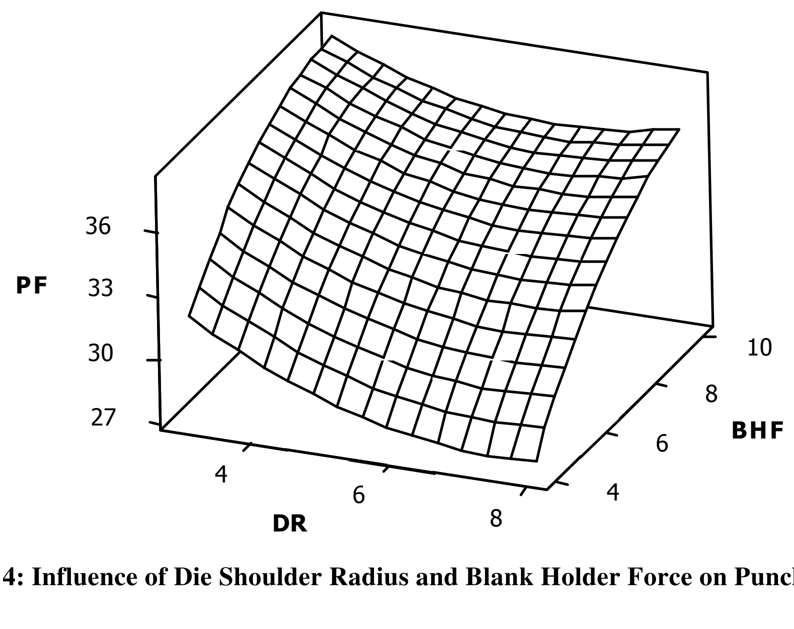

Figure 4: Influence of Die Shoulder Radius and Blank Holder Force on Punch Force

Effect of Punch Nose Radius and Blank Holder Force on Punch Force

Figure 5 shows the estimated response surface for punch nose radius and blank holder force on punch force. The punch force is unaffected by the punch nose radius up to 5 mm and then decreases slightly towards higher values of punch nose radius. But for any value of punch nose radius the punch force increases significantly with increased blank holder force. The reason has been discussed in the previous paragraph. For higher values of blank holder force, the flow of material from the flange portion is restricted. But the material is drawn into the cup wall from the punch face through the generous punch nose radius. As a result, the material strain hardens and thereby increases the required punch force.

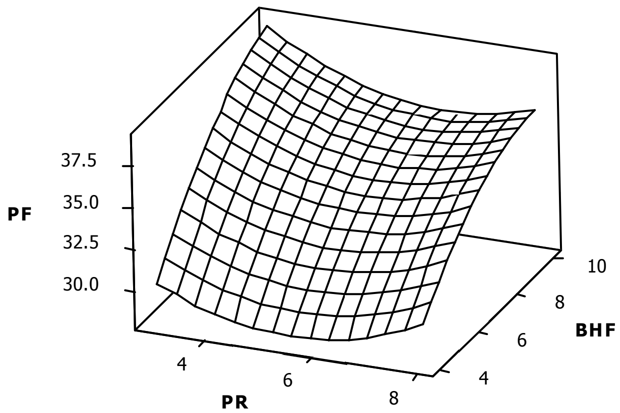

Figure 5: Influence of Punch Nose Radius and Blank Holder Force on Punch Force

Effect of Die Shoulder Radius and Punch Radius on Punch Force

Figure 6 exhibits the effect of die radius and punch radius on punch force. Increase in punch nose radius and die shoulder radius allows free flow of material to be drawn. The generous radii decrease the degree of bending and thereby decrease the punch force requirement. Also, it is observed that the effect of change in punch radius is not as significant as that of die shoulder radius. For lower values of punch nose radius, reduction in die shoulder radius significantly decreases the punch force requirement.

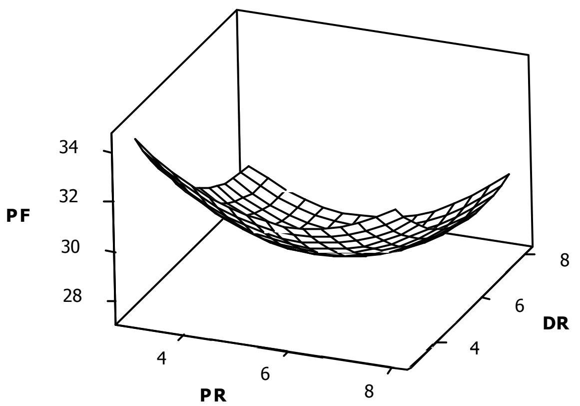

Figure 6: Influence of Punch Nose Radius and Die Shoulder Radius on Punch Force

OPTIMISATION

As discussed in section 3.1, the objective of using RSM is not only to investigate the response over the entire factor space, but also to locate the region of interest where the response reaches its optimum or near optimal value. The second order polynomial model to represent the selected parameters namely Die shoulder radius, Punch nose radius and Blank holder force were utilized to optimize the operating conditions of the parameters. The objective of the optimization is to minimize the punch force required for drawing. For minimum punch force requirement, moderately higher values of punch nose radius and die shoulder radius are required while keeping the blank holder force minimum i.e. Punch nose radius, 5.17 mm; Die shoulder radius, 6 mm; and Blank holder force 4 kN. And the minimum punch force achievable with these parameter settings is 14.51 kN.

CONFIRMATION EXPERIMENTS

Since the response surface equations were derived from quadratic regression fit, confirmation tests must be performed to verify their validity. [17]. Therefore experiments were conducted with the optimum parameter settings (Die shoulder radius of 6 mm, Punch nose radius of 5.2 mm and Blank holder force of 4 kN) in duplicate. These results are in close agreement with those predicted from the response surface analysis. This confirms that the RSM could be effectively used to optimize the process parameters in deep drawing process of a sheet material.

Table 7: Results of Validation Experiments

Ex. No.	Punch Force		% Error
	Predicted	Actual	
1	14.51	14	
2		13.8	

CONCLUSIONS

It has been observed that the punch force required for the deep drawing of AA 6061 sheet material is influenced by the variables such as Die shoulder radius, Punch nose radius and Blank holder force. The ANOVA test reveals that the die shoulder radius and blank holder force have significant effect on the punch force required for drawing. The effect of punch nose radius is insignificant. The Response surface methodology has been used to study the effect of variables such as die shoulder radius, punch nose radius and blank holder force on punch force and to optimize them for minimum punch force. It is found that the RSM is capable of predicting the punch force well within the ranges of the selected variables. Mathematical model has been developed on the basis of RSM utilizing the data form the deep drawing experiments for establishing the relationship between the punch force and the predominant parameters. Response surface plots were obtained to exhibit the influence of the selected three parameters on the response. From the response surface graphs, it is concluded that lower values of die shoulder radius and higher values of blank holder force increases the punch force significantly. A minimum punch force of 14.51 kN is exhibited in the deep drawing of AA 6061 sheet material with the statistically optimised parameters of 6 mm die shoulder radius, 5.12 mm punch nose radius and 4 kN blank holder force.

REFERENCES

1. Keecheolpark, Youngsukkim. The effect of material and process variables on the stamping formability of sheet materials. Journal of Material Processing Technology, 1995, 51: 64-78.
2. Johnson W, Mellor PB. Engineering Plasticity. UK: Ellis Horwood, Camelot Press, 1983.
3. Moshksar MM, Zamanian A. Optimization of the tool geometry in the deep drawing of aluminium. Journal of Material Processing Technology, 1997, 72: 363-370.

4. Browne MT, Hillery MT. Optimising the variables when deep-drawing C.R.I cups. Journal of Material Processing Technology, 2003, 136: 64-71.
5. Gheorghe Brable, Neculai Nanu, Elena Mioara Radu. Deep drawing tools and process optimization based on Taguchi and LMecA-Taguchi methods for the compensation of errors generated by springback. Proceedings of National Conference on Excellence Research - A way to Innovation, Brasov, 2008, 27-29.
6. Padmanaban R, Oliveira M, Alves JL, Menezes LF. Influence of process parameters on the deep drawing of stainless steel. Finite Elements in Analysis and Design, 2007, 43: 1062-1067.
7. Sheng ZQ, Jerathearanat S, Altan T. Adaptive FEM simulation for prediction of variable blank holder force in conical cup drawing. International Journal of Machine Tools and Manufacturing, 2004, 44: 487-494.
8. Leu DK. The limiting drawing ratio for plastic instability of the cupdrawing process. Journal of Material Processing Technology, 1999, 86: 168-176.
9. NUMISHEET 2002, Design innovation through virtual manufacturing. Proceedings of the 5th International Conference and workshop on Numerical simulation of 3D sheet forming processes, Jeju Island, Korea; 2002: 2:673-678.
10. Fundametals of Tool Design, American Society of Tool and Manufacturing Engineers, New Delhi: Prentice Hall, 1983.
11. Ahmad Assempour, Mohammad Gandomkar. An Energy Method for Analysing Deep Drawing Process by Simulated Annealing Optimization Algorithm. JSME International Journal, 2005, 48:95-101.
12. Myers R.H., Montgomery D.C. Response Surface Methodology. John Wiley and Sons Inc, 2002.
13. Montgomery D.C. Design and Analysis of Experiments. New York, Wiley,1997.
14. American Society of Metals Hand Book, Vol. 8, 9th Edition, Nov 1989.
15. Deep drawing process: analysis and experiment Mark Colgan, John Monaghan Journal of Materials Processing Technology 132 (2003) 35–41
16. Influence of Variables in deep drawing of AA 6061sheet, S. Raju, G. Ganesan, R. Karthikeyan Trans. Nonferrous. Met. Soc. China 20(2010) 1856-1862
17. Parametric optimization of powder mixed electrical discharge machining by response surface methodology, H.K. Kansal, Sehijpal Singh, P.Kumar Journal of Materials Processing Technology 169 (2005) 427-436