IDENTIFICATION OF KINEMATIC HARDENING PARAMETERS FOR MILD STEEL BY CYCLIC LOADING

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ABSTRACT

This report presents an identification of kinematic hardening parameters for mild steel by cyclic loading. Metal bending is one of the most common processes to change the shape of material by plastically deforming. A complete theory and reliable simulation has been developed to improve spring-back prediction. One of the areas that can be improved is to provide reliable material parameter inputs into the simulation software. The aims of this report are to fabricate new cyclic loading tool and identify of kinematic hardening parameters for mild steel by cyclic loading. Cyclic loading test have been conducted to determine the kinematic hardening parameters. The first step in the parameter identification process is to conduct the cyclic loading test and record load-extension data. The data converted to stress-strain data by using force analysis. The stress-strain data are optimized by using kinematic hardening equation. Once the stress-strain data have been optimized, the kinematic parameters are identified. The values of kinematic hardening parameters are relatively high but still acceptable because the recorded R square above 0.9.

ABSTRAK

Laporan ini membentangkan pengenalpastian parameter kinematik bagi pengerasan keluli lembut menggunakan kitaran beban. Pembengkokan logam adalah salah satu proses yang biasa digunakan untuk mengubah bentuk bahan dan mengubah bentuk plastiknya. Satu teori yang lengkap dan simulasi yang bagus telah dibangunkan untuk meningkatkan ramalan terhadap pembentukan semula. Salah satu bahagian yang boleh diperbaiki adalah menyediakan parameter bahan yang betul ke dalam proses simulasi. Tujuan laporan ini adalah mencipta alat baru bagi kitaran beban dan mengenal pasti parameter kinematik bagi pengerasan keluli lembut menggunakan kitaran beban. Ujian kitaran beban telah dijalankan untuk menentukan parameter kinematik pengerasan. Langkah pertama dalam proses mengenalpasti parameter adalah menjalankan ujian kitaran beban dan merekod nilai bacaan bagi eksperimen itu. Nilai tersebut ditukar kepada nilai tegasan dan terikan dengan menggunakan analisis daya. Data tegasan dan terikan dioptimumkan dengan menggunakan persamaan pengerasan kinematik. Apabila data tegasan dan terikan telah dioptimumkan, parameter kinematik dikenal pasti. Nilai-nilai parameter bagi pengerasan kinematik begitu tinggi tetapi nilai masih diguna kerana nilai R yang direkod melebihi 0.9.

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LIST OF SYMBOLS

α	Back stress
B,C	Hardening modulus
γ	Rate of kinematic hardening modulus
ε^{-p}	Plastic strain
s	Neutral axis
σ	stress
ρ	Radius of curvature
M	Moment
$3D$	Three dimension
F	Force from machine
$P1$	Supported force
Θ, β, a	Assumed angle
x_b	Displacement when it move
r_2	Length of holder
r_3	Length of hand part
N	Normal force

LIST OF ABBREVIATIONS

FEM	Finite element method
AISI	American iron and steel institute
CNC	Computer numerical control
ASTM	American Society for Testing and Materials
LVD	Low voltage directive
DQSK	Drawing quality silicon-killed steel
SSE	Sum of square due to error
RMSE	Root mean squared error

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

When a metal sheet is drawn over a die corner or through a drawbead, the material is subjected to bending, unbending, and rebending. Bending of sheet metal is one of the widely used processes in manufacturing industries especially in the automobile and aircraft industries. This bending process is commonly used because this process is simple and final sheet product of desired shape and appearance can be quickly and easily produced with relatively simple tool set. In bending operation, plastic deformation is followed by some elastic recovery when the load is removed due to the finite modulus of elasticity in materials.

In this project, cyclic bending test have been conducted to determine the kinematic hardening parameters. The first step in the parameter identification process is to make experimental measurements of selected values for a test specimen exposed to loading. Once data have been obtained, the identification of material parameters should correlate with the mathematical model which is integrated into an FE solver. Usually, the methods for parameter identification are based on the solution of inverse problems, and rely on optimization techniques.

1.2 PROBLEM STATEMENT

Metal bending is one of the most common operations to change the shape of material by plastically deforming. Although this process is simple but it has a problem which is spring-back. So precise prediction of the spring-back is a key to design bending dies, control the process and assess the accuracy of part geometry. A complete theory and reliable simulation has been developed to improve spring-back prediction. One of the areas that can be improved is to provide reliable material parameter inputs into the simulation software. Thus works to improve the method of determining material parameters are important and have been done by several researchers such Zhao and Lee (2002) and Omerspahic et al. (2006).

1.3 OBJECTIVES OF THIS STUDY

The objectives of this study are:

1. To fabricate new cyclic loading tool.
2. To identify of kinematic hardening parameters for mild steel by cyclic loading.

1.4 SCOPES OF STUDY

The scopes of this study are:

1. Literature review: to study basic understanding of force analysis, cyclic bending testing, experimental equipment and formula from the past researchers.
2. To design new testing tools by using solid work or auto cad.
3. To fabricate new cyclic bending testing tools by using machine involving G-code and M-code.
4. To conduct cyclic bending tests to get the data for identification kinematic hardening parameters of mild steel.
5. To analysis experimental data and use it to identify hardening parameters by using Matlab.

1.5 OVERVIEW OF REPORT

There are five chapters including introduction chapter in this study. Chapter 2 presents the literature review of previous studies includes sheet metal forming, types of bending, hardening theory, parameters involved in cyclic loading, material testing, optimization method and material selection. Meanwhile, Chapter 3 discusses design of cyclic loading tool, cyclic loading tool preparation, specimen preparation, cyclic loading test and optimization method. In Chapter 4, the important findings are presented in this chapter. Chapter 5 concludes the outcomes of this study and recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discusses about the sheet metal forming, types of bending, hardening theory, parameters involved in cyclic loading, material testing, optimization method and material selection. The most important in this chapter presents about the kinematic hardening parameters, kinematic hardening.

2.2 SHEET METAL FORMING

Sheet metal forming processes are those in which force is applied to a piece of sheet metal to modify its geometry rather than remove any material. The applied force stresses the metal beyond its yield strength causing the material to plastically deform but not to fail. By doing so, the sheet can be bent or stretched into a variety of complex shapes. There are a few examples of common sheet metal forming such as blanking and piercing, bending, stretching, stamping or draw die forming, coining and ironing and many more (Marciniak et al., 2002.). Figure 2.1 shows type of sheet metal forming.

In sheet metal forming industry, especially in sheet bending process, spring-back has a very significant role. In this process, the dimension precision is a major concern, due to the considerable elastic recovery during unloading which leads to spring-back. Also, under certain conditions, it is possible for the final bend angle to be smaller than the original angle.

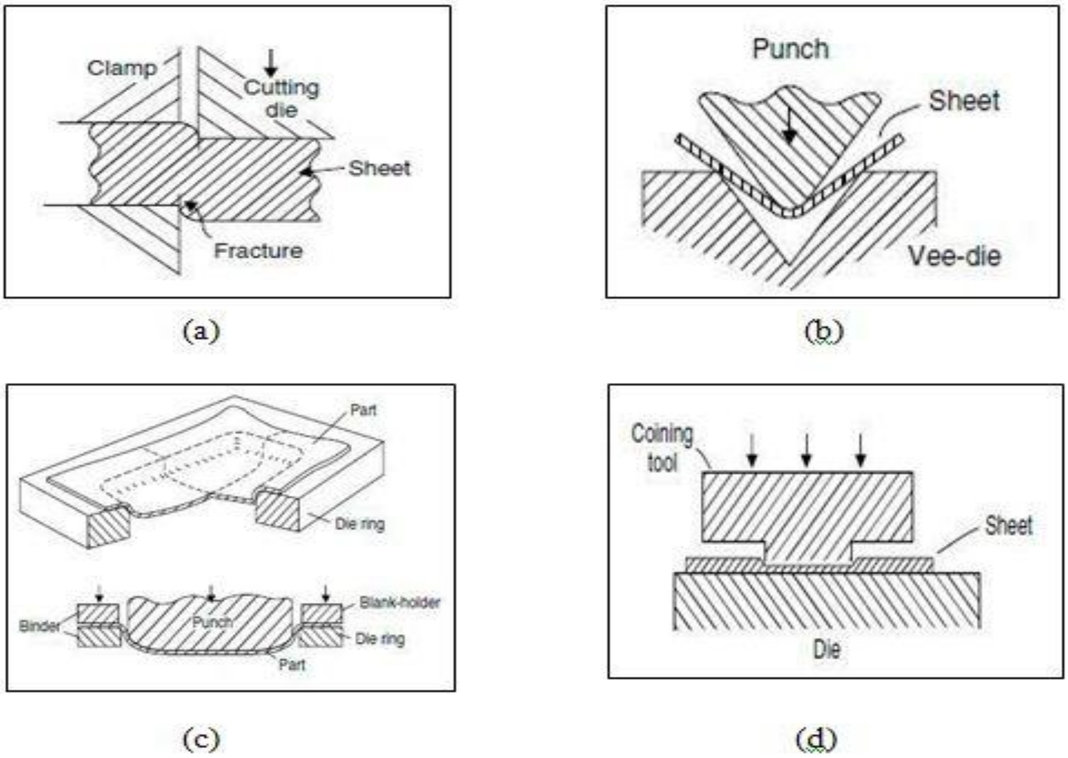

Figure 2.1: (a) Basic cutting process of blanking a piercing. (b) Example of sheet metal bending process. (c) Typical part formed in a stamping or draw die. (d) Thinning a sheet locally using a coining tool.

Source: Marciniak et al. (2002)

2.3 TYPES OF BENDING

There are several types of bending that commonly used in the industries such as air bending, bottoming, and U-bending. A bending tool must be decided depending on the shape and severity of bend (Boljanovic, 2004). Air bending is a bending process in which the punch touches the work piece and the work piece does not bottom in the lower cavity. As the definition of springback, when the punch is released, the work piece springs back a little and ends up with less bend than that on the punch. There is no need to change any equipment or dies to get different bending angles since the bend angles are determined by the punch stroke. Figure 2.2 shows air bending process.

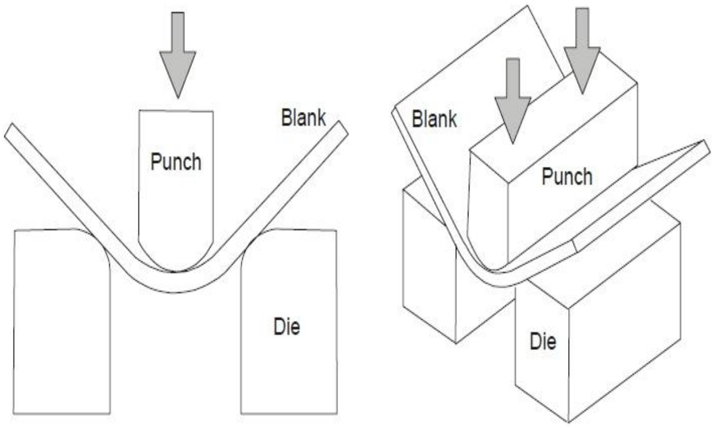

Figure 2.2: Air bending process

Source: Diegel et al. (2002)

Bottoming is a bending process where the punch and the work piece bottom on the die. In bottom bending, spring back is reduced by setting the final position of the punch such as that the clearance between the punch and die surface is less than the blank thickness, the material yields slightly and reduces the spring back. In Figure 2.3 shows bottoming process.

U-bending is performed when two parallel bending axes are produced in the same operation. A backing pad is used to forces the sheet contacting with the punch bottom (Marciniak et al., 2002). Generally U-bending process can be divided into two steps, loading and unloading. In the loading step, the punch will completely moves down and the metal is being bent into the die. During this step, the work piece undergoes elastoplastic deformation and temperature increase under frictional resistance. Figure 2.4 shows sheet metal U-bending process.

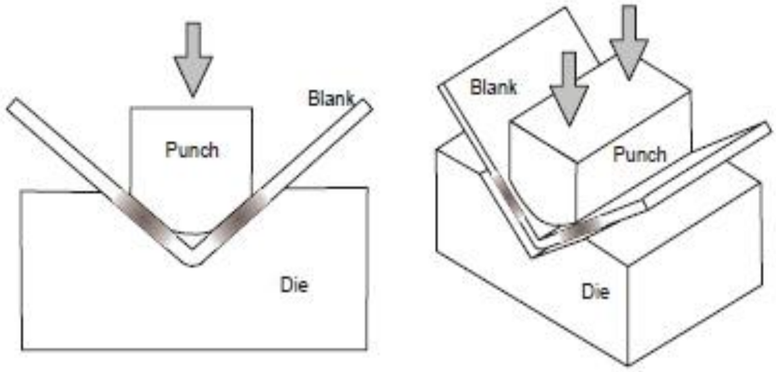

Figure 2.3: Bottoming process.

Source: Diegel et al. (2002)

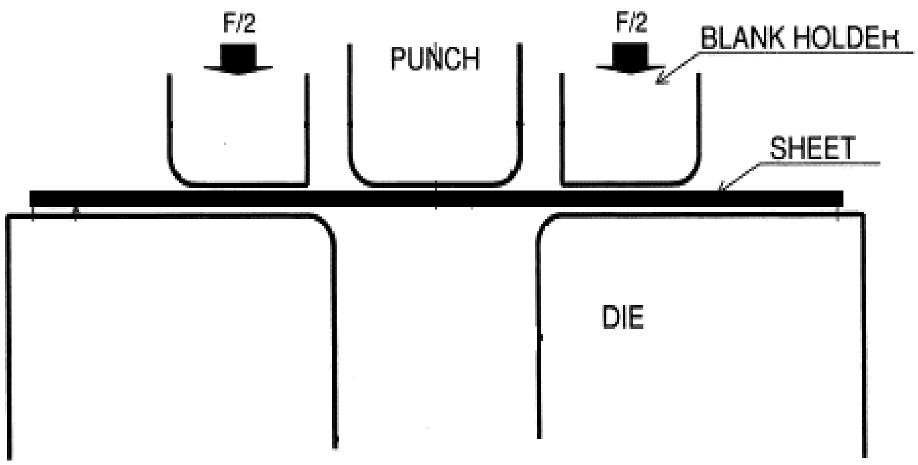

Figure 2.4: Sheet metal U-bending process

Source: Bakhshi-Jooybari et al. (2009)

For the second step which is unloading step, the deformed sheet metal is ejected from the tool set and metal was experiencing the residual stress release and the temperature drop to reach a thermo-mechanical equilibrium state (Cho et al., 2003). U-bending process is often used to manufacture sheet parts like channels, beams and frames. In this process, the sheet metal usually undergoes complex deformation history such as stretch-bending, stretch-unbending and reverse bending.

Many methods such as analytical method, semi-analytical method and finite element method (FEM) have been applied to predict the sheet springback for all type of bending. According Samuel (2000), applied FEM to simulate the forming and springback process of sheet U-bending and reviewed the effects of numerical parameters, tools geometry and process parameters on the predicted accuracy of springback. One of the ways to predict accuracy of springback is improve material hardening parameter by design a new testing tool.

2.4 HARDENING THEORY

There are many hardening theory to prove stress-strain curve based on isotropic hardening theory, kinematic hardening theory and combination of isotropic and kinematic hardening theory. Kinematic hardening theory has been improved by some authors for example Lemaitre and Chaboche and Armstrong and Frederick.

2.4.1 Lemaitre and Chaboche Hardening Theory

The non-linear kinematic hardening component describes the Bauschinger effect by describing the translation of yield surface is stress space through the back stress such that straining in one direction reduces the yield stress in the opposite direction. This law is defined as an additive combination of a linear term and relaxation term which introduce the non linearity using Equation (2.1):

$$\partial\alpha = \frac{C}{\sigma_0}(\sigma - \alpha)\partial\varepsilon^{-p} - \gamma\alpha\partial\varepsilon^{-p} \tag{2.1}$$

Integration of the kinematic hardening law for monotonic loading in one dimension yield as Equation (2.2):

$$\alpha = \frac{C}{\gamma}\left(1 - e^{-\gamma\varepsilon^{-p}}\right) \quad (2.2)$$

where α is back stress, C is a kind of hardening modulus and γ defines the rate at which the kinematic hardening modulus decrease and ε^{-p} is plastic strain.

2.4.2 Armstrong and Frederick Hardening Theory

Armstrong and Frederick added a recovery term to the linear hardening rule of Prager and proposed a nonlinear hardening rule in the following form as Equation (2.3):

$$\partial\alpha = \frac{2}{3}B\partial\varepsilon^{p} - \sqrt{\frac{2}{3}\partial\varepsilon^{p}\partial\varepsilon^{p}} \quad (2.3)$$

The added term, takes into account a fading memory of the plastic strain path. Starting with a plastic modulus of $B \pm (3/2)$ ca in a uniaxial loading condition, ax eventually stabilizes at a value of $(2/3)B/c$. Incorporating the recovery term was a major development eliminating the deficiencies of linear and multilinear hardening rules. Uniaxial ratcheting can be simulated by this model. However, since few material constants are available to produce an acceptable shape of the stress–strain curve, Armstrong and Frederick model is no longer considered suitable for ratcheting prediction.

2.4.3 Bauschinger Effect

Bauschinger effect is the most common nature in the change of deformation path as investigated precisely by the torsion of a bar or tube. It is, however, difficult to achieve the cyclic path of deformation in sheet metals. The planar simple shear test Eli makes it possible to measure the Bauschinger effect quantitatively. The Bauschinger effect is characterized by the low yield stress at the beginning of reversed deformation path as compared with the resistance to deformation in the monotonic path. But it is also important to pay attention to the following characteristics of Bauschinger curve.

2.5 PARAMETERS INVOLVED IN CYLIC LOADING

According to Lemaitre and Chaboche research, the kinematic hardening parameters are identified by using the Equation (2.2). Where α is back stress, C is a kind of hardening modulus and γ defines the rate at which the kinematic hardening modulus decrease and $\bar{\varepsilon}^{p}$ is plastic strain. These parameters can be determined by cyclic bending test for a flat sheet metal. Conventional tension-compression test is not suitable for identification kinematic hardening parameter because it difficult to set up due to the buckling of the sheet specimens (Zhao et al., 2002).

2.6 MATERIAL TESTING

2.6.1 Tensile Test

The identification of parameters that describe material hardening in particular can be made by conventional tension-compression uniaxial experiments. As the buckling of the specimen in compression obstructs this type of experiment, the material parameters for mixed hardening have usually been determined by the cyclic torsion of metal bars or tubes**.** According to Yoshida et al. (2002), they use five pieces of the sheets were adhesively bonded together before machining so that the thickness of the specimen was 5.0 mm in order to prevent the buckling. Kuwabara et al. (1995) performed experiments on mild steel sheets and an aluminum alloy sheet under in-plane reverse deformations using a special device for preventing the buckling of the sheets. Although, their experimental data were at large strain, it seems that their interests were mostly related to the permanent softening during a reverse deformation, but not either the transient softening or cyclic hardening characteristics.

2.6.2 Cyclic Loading Test

Zhao et al. (2002) suggested an identification of the hardening characteristics by a cyclic three-point bending test. Hence, this identification is a basis for the work described in the current paper. The intention of the research is to develop a simpler experimental set up, and a methodology for identification of hardening parameters for rate-dependent and -independent materials. Omerspahic et al. (2006) also identify of material hardening parameters by using cyclic bending test. Figure 2.5 shows the experimental setup used in the cyclic bending test. The error in displacement reading is estimated as 0.02 mm and in force reading as 2 N. Dimension for specimen tested as 1 × 30 × 250 mm (thickness × width × length).

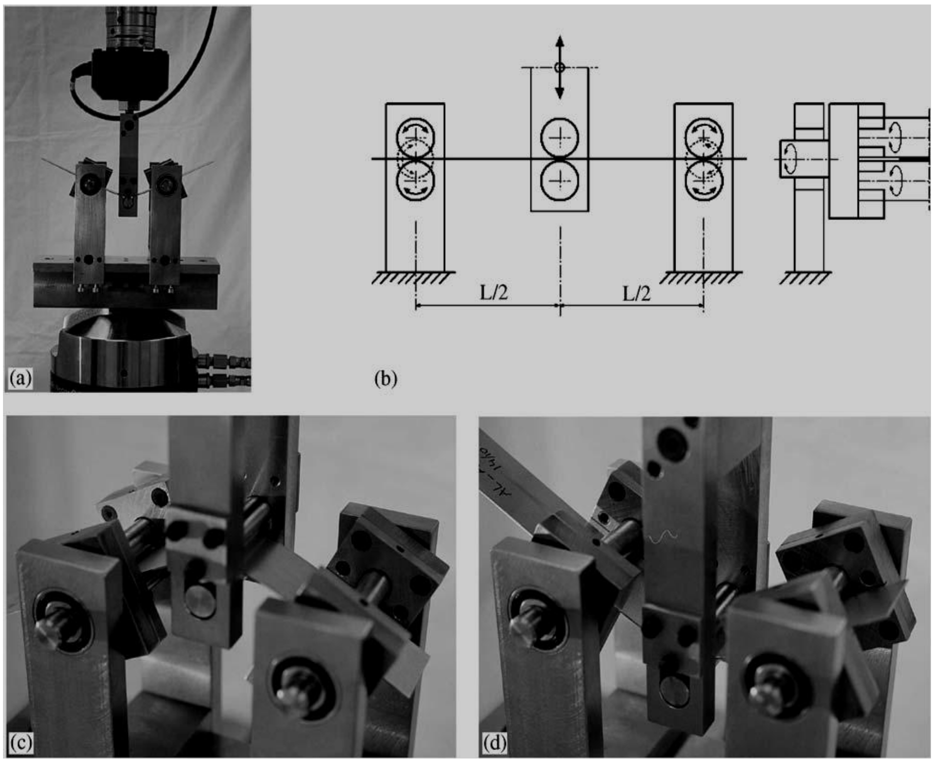

Figure 2.5: Experimental set-up used in the three-point cyclic bending tests: (a) an overview of the set-up; (b) sketch of the test arrangement; (c) and (d) close-up views of the specimen deflected in two directions.

Source: Omerspahic et al. (2006)

The advantage of this test is that it is simple to perform, and standard test equipments can be used. The test has then been simulated by using Finite Element Method and the material parameters have been determined by finding a best fit to the experimental results by means of a response surface methodology (Eggertsenet and Mattiasson, 2011). An alternative method is the tensile-compression test of a sheet strip. In practice such a test is very difficult to perform, due to the tendency of the strip to buckle in compression. However, a few writers have reported that there are substantial differences between hardening parameters determined from bending tests and those determined from tensile and compression tests.

2.7 OPTIMIZATION METHOD

Optimization means that a mathematical discipline that to find minimum and maximum of functions. Optimization originated in the 1940s, when George Dantzig used mathematical techniques for generating programs for example training timetables and schedules for military application. Now optimization comprises a wide variety of techniques from Operations Research, artificial intelligence and computer science, and it is used to improve business processes in practically all industries. There are many optimization methods to minimize curve fitting problem while identification the kinematic hardening parameter such as Levenberg-Marquardt method and least-square optimization method.

2.7.1 Levenberg–Marquardt Method

In mathematics and computing, Levenberg–Marquardt method provides a numerical solution to the problem of minimizing a function generally nonlinear over a space of parameters of the function. This method is a very popular curve-fitting algorithm used in many software applications for solving generic curve-fitting problems.

2.7.2 Least-Square Method

The method of least squares is a standard approach to the approximate solution of over determined systems such as sets of equations in which there are more equations than unknowns. Least square means that the overall solution minimizes the sum of the squares of the errors made in the results of every single equation. The most important application is in data fitting.

2.8 MATERIAL SELECTION

Selecting material for engineering application is important to make sure that material is suitable for the products. In this study, the mild steel sheet metal has been selected as a material to perform the experimental and analysis for cyclic bending test. Mild steel generally refers to low carbon steel; typically the AISI grades 1005 through 1025, which are usually used for structural applications. With too little carbon content to through harden, it is wieldable, which expands the possible applications. Low carbon steel contains approximately 0.05 to 0.25% carbons and mild steel contains 0.16 to 0.29% carbons. Therefore, it is neither brittle nor ductile. Mild steel has a relatively low tensile strength, but it is cheap and malleable, surface hardness can be increased through carburizing. Table 2.1 shows the chemical composition of mild steel.

Table 2.1: Chemical composition for mild steel.

SPCEN	C	Si	P	S	Mn	T-Al	S-Al	Ti	Nb
1005	<0.005	0.013	0.009	0.012	0.130	0.035	0.032	0.050	<0.005

Source: Zhao et al. (2002)