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UNIVERSIDADE ESTADUAL PAULISTA
CAMPUS DE GUARATINGUETÁ
Faculdade de Engenharia

RESEARCH PLAN

GRADUATE PROGRAM IN MECHANICAL ENGINEERING

Field of Study: Materials

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COURSE OF STUDY (ACADEMIC DEGREE): Doctorate in Mechanical Engineering	

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RESEARCH TITLE:

Microstructural characterization in advanced high strength steels subjected to springback effect.

Etude microstructurale d'aciers innovants à haute résistance soumis à des effets de retour élastique.

ABSTRACT:

In this project, it is planned to carry out a complete microstructural characterization of advanced high strength steels (AHSS) currently used in the automotive industry. These steels have an elastic return, called springback effect, during the conformation of parts. This springback is the main problem of this family of steels during the production process of the structural components of the automotive industry: especially for dimensional problems in automotive structural components. It is therefore necessary to evaluate changes in microstructure during the stages of conformation in order to know precisely the microstructural and mechanical behavior of material after being subjected to this effect. Finally, forming strategies may be developed in order to predict the behaviour of this family of steels during plastic deformation to decrease or eliminate the springback effect.

Steels studied in this research work are currently used by all major automobile industries, wich are dual-phase, low-carbon, bake hardening and interstitial free steels.

RESEARCH OBJECTIVES:

1 - Characterization of the mechanical anisotropy of these steels;

2 - Study of the influence of metallurgical variables (size and morphology of grain, texture, nature of grain...);

3 - Evaluation of springback by macro bending tests and in situ bending tests using SEM;

4 - Determination of the microstructural changes after mechanical tests (morphology of grain, calculation of residual stresses and the stored elastic energy after forming process) in function of the rate of deformation.

DESCRIPTION:

Justification of the proposal for the theme's design

Due to direct and indirect damage to the ecosystem caused by burning fossil fuels, the automotive industry has been facing the need to reduce the weight of their products to minimize fuel consumption, thus decreasing the cost and possible environmental aggressions caused by the use of such products. Thus, the next-generation automobiles must be lighter, economical, safer and less polluting (GRITTI et al., 2002).

The automotive industry adopted measures such as: reducing the size of the vehicles, replacement of materials traditionally used with aluminum and plastic, and replacing ordinary carbon steels. Therefore, steelmakers, with the intention of providing automakers advanced high-strength materials, have been ensuring the increase of their structural integrity, with an increased resistance to shock and a lower cost for the final product (KISHIDA, 2000).

Of all industries that produce consumer durables, the automotive industry is the one that has promoted advances in the metallurgical developments of steels the most during the latest decades. This is due to the fact there is fierce competition between automobile industries, challenging their suppliers to continuously meet the demand for better quality, lower cost and better efficiency for automotive assembly lines (CANGUE, 2002). In addition, any other material offers as much mass reduction capacity and reducing costs, coupled with significant improvements in the structural performance of a vehicle, as steel (AUTO/STEEL PARTNERSHIP, 1995).

From the 90's, advanced high-strength steels have been emerging (AHSS). The increased level of mechanical resistance of products leads to a reduction of their drawability, but with the use of suitable microstructures, it is possible to minimize the loss of ductility under higher levels of mechanical resistance (GORNI, 2008).

However, the widespread use of AHSS in the automotive industry is limited due to challenges in formability, plates, tool life and elastic return (springback). The springback is the main problem that compromises the mass production of automotive structural components with AHSS (PLACIDI et al., 2008).

The springback is identified as a change that occurred in the shape of the piece after its removal from the forming tool, due to a redistribution of residual elastic tensions (KEELER, 2009). Thus, predicting the occurrence of springback during part design is fundamental in order to seek solutions to reduce the problem.

Motivation

Once the springback effect is regarded as the main problem of AHSS in production processes of structural components in the automotive industry, it is necessary to evaluate the possible microstructural changes caused by the effect in order to precisely define the microstructural and mechanical behavior of materials after being subjected to such an effect, and possibly form strategies to predict the behavior of the steel during their plastic deformation in order to eliminate or reduce the springback effect.

The four types of steels studied in this work are used by all major automotive industries, currently being dual phase, low carbon, bake hardening and interstitial free because they are high-strength steels. Such materials feature mechanical characteristics that are suitable for use in industries but, at the same time, they present dimensional problems due to the springback effect. Thus, it is necessary a reproduction of this effect through mostly used tests in industry by comparing them in terms of a reduction of this effect.

Most studies dealing with the springback effect aim at simulating their occurrence through finite element techniques and appropriate computational software for this purpose. Due to the scarcity of jobs in the literature correlating the springback effect with the microstructure of the material, it is essential to make a correlation between the possible microstructural changes and their mechanical properties in materials subjected to such an effect in order to create a micrographic identification for each degree of material deformation, featuring the springback effect on the microstructure with accuracy.

Research proposal description

In this project, it is intended to make up a complete microstructural characterization in advanced high-strength steels applied as raw material in the production of vehicles when subjected to springback effect.

In this context, it is inserted the development of new advanced high-strength steels in line with the Ultra Light Steel Auto Body-Advanced Vehicles Concept project (ULSAB-AVC), founded in 1994, which includes, besides the ultralight bodyshell, the development of coverage and suspension panels – with which concepts were developed taking into consideration the application of new types of steels aiming at the production of safer, economically viable and efficient vehicles with respect to fuel consumption for the 21st century. (COVINO, 2000; ANDRADE, 2000).

Mechanical characterization of the springback effect will be held through two mechanical conformation tests: three-point bending in air and in situ bending tests. These two tests will be compared by means of the springback angle values obtained to determine the severity of each test. In addition to the mechanical properties of the material defined by the traction test, special attention will be given to the material anisotropy index which measures the resistance of the material subjected to the thickness reduction when plastically deformed (MORAIS, 2001).

The microstructural characterization is going to be performed by optical and scanning electron microscopy, using different chemical reagents and digital image processing techniques in order to obtain precise values of the grains'aspect ratio. It is a measure of the relation between the largest and smallest dimension of a grain and it will be related to the index of anisotropy for different bending angles.

From the microstructural characterization of each material subjected to the springback effect, it will be possible to generate a micrographic identification of materials for each bending angle, and the correlation of their microstructure and mechanical magnitudes will indicate the final mechanical condition of each material after the springback effect.

Finally, it will be possible to define the real mechanical conditions of a material only through observing its micrographs. This will be a great contribution to the study of metallography applied to mechanical bending of steels.

METHODOLOGY:

Already designed methodology carried out and to be concluded in Brazil

In this work, it is used dual phase, bake hardening, low carbon and interstitial free steels, commercial products, provided by the automaker industry (PSA Peugeot Citroën Brazil) and by ironwork (ArcelorMittal Brazil). The material was supplied by the companies in the form of plates of 500 mm x 500 mm, varying from 0.5 to 2 mm thick for each class of material.

From the supplied steels, specimens were extracted for running tensile tests that were manufactured in accordance with ASTM standard E8M, while the specimens for metallographic analysis were made according to ASTM and 3-10 (2007). From the mechanical tests, it was possible to get properties such as limit of tensile strength, yield stress, elongation, hardening index and index of anisotropy or Lankford coefficient.

The microstructural characterization to be held will involve techniques associating concepts of digital image processing that will allow measurements of parameters such as area of grains, morphology, aspect ratio, volumetric fraction of phases, among others. The software used for the measurement of such parameters will be the ImageJ.

Bending test chosen to simulate the springback effect is described below.

1. Three-point bending in air made in adaptation to the method parameters of unconstrained cylindrical bending test, presented at the Numisheet Conference 2002. In this experiment, the specimen was submitted to cylindrical body punch, being that this has 5 mm radius, and the distance between the supports of the mold is calculated according to the ASTM E290-09 standards.

A part of this test (macro bending test) was carried out on a universal testing machine, SHIMADZU, Autograph model AG-X 50kN Department of Materials and technology of FEG/UNESP. The remaining tests will be conducted at ENIT.

This bending test will also be conducted in situ with the aid of scanning electron microscopy (SEM) in the Laboratoire Génie de Production of Ecole Nationale d'Ingénieurs de Tarbes – ENIT.

In both tests, the specimens were submitted to conformation until the internal bending angle achieved predetermined values. The selected values for the internal bending angle were: 30º, 60º, 90º and 120º, respectively, for each bending, using six repetitions for each angle in the same material. These values were chosen to offer a smoother deformation from 120º up to a more severe deformation of 30º. Each one of these selected angles was achieved through a punch displacement control on the y-axis with a descent speed of 0.5 mm/s. The punch was taken from specimen twenty seconds after reaching the desired bending angle, and then the new bending angle was measured to check whether there were springback effect or not.

For the measurement of the new bending angle, in the case of macro bending test, it was used the Image J software 1.45 for processing images shot in an Olympus digital camera. These measurements were taken for periods of 12 h, 24 h, 48 h and 72 h after bending. Once you have completed the 72 h after the mechanical bending, the resulting final bending angle was subtracted from the initial bending angle, which are 30º, 60º, 90º or 120°, and such subtraction resulted in the total angle of the effect.

Graphics of stress versus strain and graphics of applied forces on the deformation versus the degrees of the angles formed are going to be built.

From the stress versus strain plot, the stress used in the elastic zone deformation and the stress used in the plastic zone deformation will be obtained. And the sum of these two will be subtracted from the total applied stress and its result (residual elastic stress) will be compared with the values of the springback angles. A correlation between the residual elastic stress and the area of the grain boundaries for each material will be also established.

The greater or lesser springback effect will be correlated with the microstructural characteristics and with the resilience property of each material.

The mechanical property of anisotropy will be measured before and after the mechanical bending and will be correlated with the aspect ratio of each material. As well as the area of the grains and the grain boundaries before and after the conformation will be measured and correlated to the residual elastic stress obtained during the bending process.

Methodology to be performed in France

The microstructural characterization to be held will involve techniques associating concepts of digital image processing that will allow measurements of parameters such as area of grains, morphology, aspect ratio, volumetric fraction of phases, among others. The software used for the measurement of such parameters will be the Image J.

For the microstructural characterization of the material as received, the specimens will be analyzed in a longitudinal direction (direction of lamination), a transversal one, and the other at 45°. The region of steel sheets chosen to obtain the specimens from the material after it went through the springback effect will be that on which it will form a curvature due to bending, called as z axis of the parabolic trough. The specimens will be cut in this region, by dividing steel sheet in half and embedding the material in order to expose the inner part on the surface, obtaining, then, inlaid specimens exposing the longitudinal direction, the transverse direction and the direction at 45°. It will also be prepared specimens by exposing the longitudinal direction of the bottom surface of the z axis, assuming that the grains in such region will be the most affected ones by mechanical bending.

All specimens will be analyzed by optical microscopy. Some specimens will be analyzed by scanning electron microscopy (SEM).

Texture specimens and strain across the grain may also be determined by EBSD - electron backscattered diffraction technique in the scanning electron microscope.

To complete the study, it will be carried out in situ mechanical bending tests in the SEM in order to analyse the microstructure in certain bending angles in more details.

This last step will be a differentiator for the project, primarily by the fact that at ENIT, the joint adviser, already has experience in this procedure.

This way, it will be created a micrographic identification of each material for each bending angle after the springback effect, and a prediction of the mechanical behavior of a given material from observation of its micrographs will be possible.

For the completion of the project, taking into account the relevance of the theme and of scientific and technological interest, the final results will be published in journals specifically on microstructural characterization of the analysed materials and their correlation with the springback effect, in addition to the publication of full papers in national congresses.

PLACES OF COMPLETION OF WORK:

All the specimens for the mechanical tests were machined at the Workshop in Support for Research in DMT/FEG/UNESP, created by FAPESP project (96/10289-0).

Tensile tests and a part of macro bending tests were executed in the laboratories of DMT/FEG/UNESP, as they were already successfully performed by a previous research.

Based on a previous research developed by the research group of applicant researcher, it can be affirmed that an intense refinement of the specimens preparation techniques for a microstructure characterization must be carried out, especially regarding their cleaning and polishing, as well as in the procedures of chemical etching. This step will be performed in Laboratoire Génie de Production of Ecole Nationale d'Ingénieurs de Tarbes – ENIT, belonging to the Institut National Polytechnique de Toulouse (INP Toulouse) – France.

Optical microscopy, scanning electron microscopy techniques, EBSD, macro bending tests remaining and in situ bending tests in the SEM will be held in Laboratoire Génie de Production of Ecole Nationale d'Ingénieurs de Tarbes – ENIT – France.

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SCHEDULE OF ACTIVITIES:	
Activities	**Country of execution of the research**
A. Bibliographic research	**Brazil and France**
B. Donation of materials and manufacture of specimens (tensile tests and bending tests)	Brazil
C. Mechanical characterization (tensile tests) of materials as received	Brazil
D. Realization of macro bending tests	Brazil
E. Metallography (specimens preparation and chemical etching)	**FRANCE**
F. Optical microscopy of materials as received and after undergoing conformation	**FRANCE**
G. Mechanical characterization (anisotropy) of materials as received and after undergoing conformation	**FRANCE**
H. Realization of EBSD techniques. Scanning electron microscopy with image analysis (qualitative and quantitative analysis) of materials as received and after undergoing conformation	**FRANCE**
I. Realization of macro bending tests remaining and in situ bending tests in the SEM	**FRANCE**
J. Performing statistics calculations and preparation of graphics	**Brazil and France**
K. Further testing and analysis of results of images	**Brazil and France**
L. Publication of papers in journals and congresses	Brazil
M. Composition of doctoral dissertation and preparation of defence of doctorate	Brazil

SCHEDULE OF ACTIVITIES:

		2	0	1	2						2	0	1	3										2	0	1	4										2	0	1	5								2	0	1	6		
	A	S	O	N	D		J	F	M	A	M	J	J	A	S	O	N	D		J	F	M	A	M	J	J	A	S	O	N	D		J	F	M	A	M	J	J	A	S	O	N	D		J	F	M	A	M	J	J	A
A	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X									
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H																										X	X	X	X	X	X		X	X																			
I																													X	X	X		X	X	X																		
J																										X	X	X					X	X	X	X																	
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M																																							X	X	X	X	X	X		X	X	X	X	X	X	X	X

FRANCE

RESEARCH TITLE:

Microstructural characterization in advanced high strength steels subjected to springback effect.

Student's signature
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Joint advisor's Signature (France)
PhD Joël Alexis

France, november...30..., 2013.
Guaratinguetá, november ...29..., 2013.

Reviewed by professor PhD Joël Alexis in October 06, 2014.

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PhD Joël Alexis