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EXPERIMENTAL APPARATUS FOR SHEET METAL HEMMING ANALYSIS

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Abstract

A new portable system for experimental investigation in the process of sheet metal hemming was developed. In the introduction, information was provided about the need to use machine vision systems to solve problems that occur in the process of hemming. Then, a test stand designed for the practical implementation of a three-step hemming process was presented. Among the different vision systems available, a method using laser light scanning for reconstruction of the geometry of the examined hemmed sample was selected. An optical system for studies of the measurement technique and a method of image analysis used in the described example of the plastic forming process were presented. In this process, first, the test sample image is recorded, and it is analysed next to obtain information about an outline of the deformed line. Further in the text, a new method proposed by the author for the reconstruction of a 3D outline of the hemmed sample was disclosed along with a technique to calculate the value of strain on its surface. Finally, a portable measurement system for quality control of the hemmed surface edges was shown for the industrial application.

Key words: strain analysis, sheet metal hemming, experimental analysis, vision based measurement

1. INTRODUCTION

The subject of the paper relates to the proposed complex solution for quantitative and qualitative control of a three-step hemming process (figure 1). Hemming is the sheet metal forming process, which consists in flanging, followed by pre-hemming and final hemming classified by Muderrisoglu et al. (1996). At the final stage of the process, the end part of the sheet rolled over to the inside onto itself forms an angle of 180 degrees with the remaining base part of the sheet. This process is applied in the final stage of the car body production, and is used for two purposes: (i) to join together two parts of the sheet metal, where one sheet fills a gap between the bent edges of another sheet, and (ii) as a finishing operation by which the raw sheet edge is hidden inside the item shaped. Yet, the mechanism of the hemming process is much more complex than it might be judged from the description of a pure bending process. One of the example of the hemming process includes the door hinges, where different deformation mechanisms are operating.

It is a well known fact that properly designed and performed, each stage of the hemming process can effectively eliminate or at least minimise the majority of defects caused by metal deformation. For this reason, the whole range of parameters governing the process of forming should be subject to very carefully monitoring, remembering that it affects the final product quality, mainly in terms of gaps existing between the rolled over edges of adjacent components, or folds and fissures, i.e. the roll-in, roll-out, warp and recoil described by Livatyaliet

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et al. (2000). Therefore, to minimise errors occurring when the process of hemming is designed, a comprehensive understanding of the process itself is necessary to which hitherto not much attention has been paid. This can be achieved by improving the already existing techniques or developing the entirely new ones, to achieve better insight into the forming process. The ultimate goal is to determine experimentally the process limit parameters, the process kinematics, and the geometry and surface quality obtainable in the operation of sheet metal hemming on the basis on research performed by Swillo et al. (2005 and 2006). Due to this it will be possible to evaluate the results of an inspection through comparison of model results with the experimental data generated by a specially developed vision system. The studies will enable quick and accurate analysis of the process of hemming for any geometric and material-related parameters found in the selected segments of a car body. In contrast to the time-consuming and less accurate methods of assessment based on an optical system, the proposed method using a vision system will allow an immediate analysis of the finished product.

2. EXPERIMENTAL APPARATUS

A special column-like shaped device was designed and built to perform the hemming process; an option has also been provided for the quick setup of the device (figure 2a). The device consists of the following main parts: two columns fixed in the bottom plate, guide sleeves fixed in the top plate, and a forming tool. The forming elements include a die with an option allowing changes in the bending radius and a punch with an option allowing changes in the pre-hemming angle. The concept of the device for the hemming process assumes an easy replacement of the forming elements. Moreover, the use of punch guides in the device allows precise control of the punch travel with the possibility to measure the clearance between the die and the punch. This solution allows precise determination of the forming process parameters, and therefore has been used in the studies of a numerical modelling of the hemming process. The material used in the hemming test was aluminium sheet (A1050). Figure 2b shows the measurement stand for the hemming tests equipped with two systems: a vision system for recording of the process run and data acquisition from the force sensor, and a displacement sensor. To study the hemming process (curve surface and curve edge), a special hydraulic press (applied previously in stud-

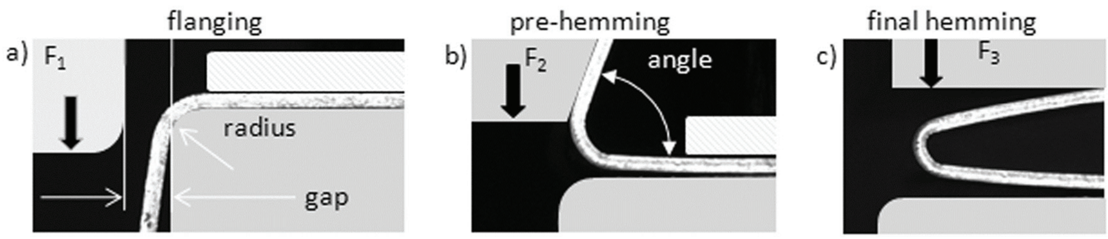

Fig. 1. Schematics of the three steps hemming process: a) flanging, b) pre-hemming, c) final-hemming.

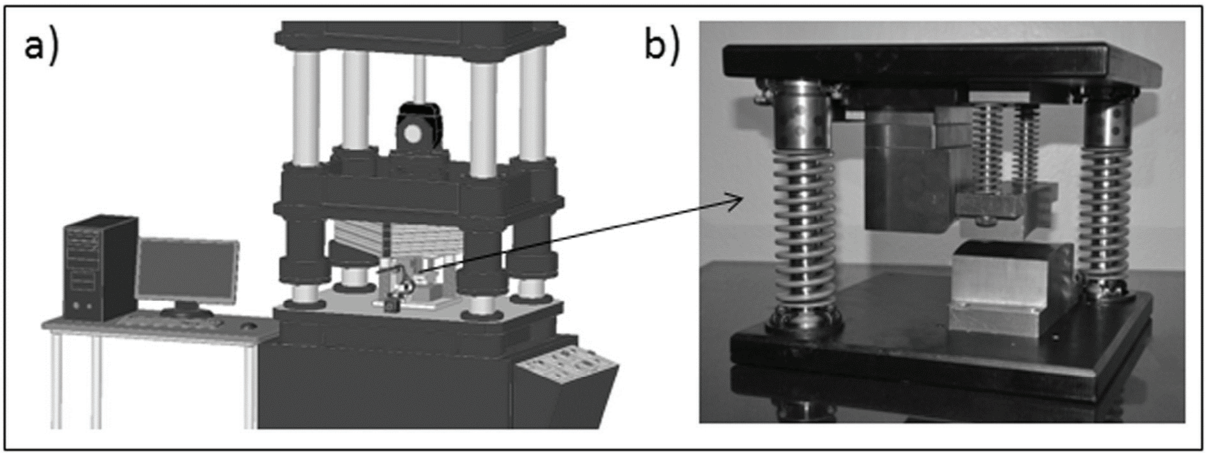

Fig. 2. Experimental apparatus for hemming process: a) schematic of the designer apparatus, b) hemming tool.

ies of the flat surface and straight edge, by Świłło et al. (2011, 2012) was used. Due to its high stiffness, large working space, the maximum pressure of 40kN and low punch operating speed during forming, the press allowed obtaining similar forming conditions as the conditions used during industrial hemming of the sheet metal. The hemming test was carried out using a force measurement system in the form of an axial strain gauge mounted on the model press. Used in combination with the displacement sensor attached to the press, it enabled full control of the hemming force in function of the punch position. The measurements were carried out in a Matlab/Simulink environment that allows for block construction of the performed measurement tasks based on image processing and data acquisition originally proposed by Higham and Higham (2005), and Chen et al. (1999).

vices such as a feeler gauge. The repeatability in such cases is unsatisfactory. This statement leads to the conclusion that it is necessary to develop a vision system based on an advanced method of measurement and control of all process parameters. Therefore, the aim of the project is to use all the three main parameters of the process, that is:

– deformation during forming,
– change in the shaped product geometry,
– quality of the shaped surface.

All these parameters can be used in a comprehensive assessment of the hemming process quality referred to the structural parts of a car body design. The use of these three parameters demands further development and implementation of advanced measurement techniques allowing for their full identification. Thus, the final task of the running project was to design and manufacture of a portable vision measurement system to allow inspection of the chosen three parameters.

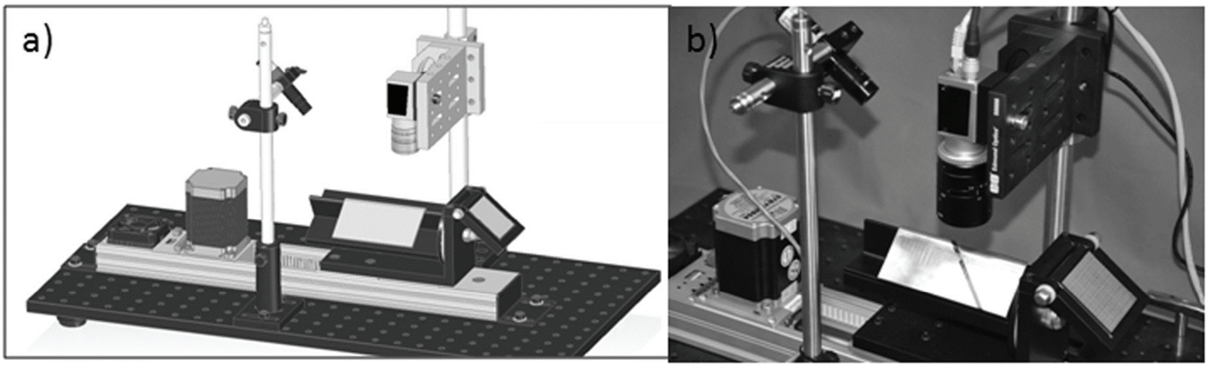

Fig. 3. *Vision based measurement for hemming: a) schematics for the strain and geometry analysis, b) stationary vision system.*

3. METHODOLOGY OF HEMMING ANALYSIS

Based on the industrial experience and numerous research results, it becomes obvious that the final quality in the hemming process depends on a complex interaction between the material properties, geometry and process parameters, as reported in many works on this subject. The studies discussed above, and a number of other related works (Livatyali et al., 2000 and Graf & Hosford, 1994) clearly indicate the need to search for proper relationships between the product quality, determined by the presence or absence of such defects as cracks or folds in the sheets, and the geometry of the hemming process. It should be remembered that all of the above indicated features directly affect the final evaluation of the product quality and functionality, and thus indirectly the quality and functionality of the whole car. The methods used commonly in the industry to assess the quality of such products are either visual methods or methods using simple de-

3.1. Geometry and deformation measurement

The measurement of deformation in a bent sample, where the bending angle is between 20 to 180 degrees, is a serious problem due to high localisation of the non-linear in nature distribution of deformation. In samples with a thickness of 1 mm, the maximum deformation will be concentrated in an area of the size of micrometres. Consequently, the selected method to measure deformation should be characterised by both high resolution and high accuracy with the ability to determine the deformation in different variations of the hemming process (the curved surface and the curved hemmed edge - 3D). Therefore, the strain measurement algorithm, presented by the author in this study, is based on a previously proposed solution by Swillo et al. (2005), co-called ALM (Angle Line Method). This method allows a continuous strain determination in the examined sample, where the discretisation of measurements is imposed only because of the image resolution. Strain measurement using this method involves the application of a simple pattern-line onto the examined object in the area of the expected deformation, and the line should be applied at a certain angle. Then, to identify the line, a numerical image processing is used, allowing full automation of the strain determination technique. The advantage of this method over the traditional techniques using different mesh geometry is the process of the measurement discretisation, which in the case of the proposed method has no major restrictions on account of the pattern geometry used. In addition, another advantage of ALM is its simplicity in use, involving a simple formula, which can be written with just any pen. Next, as an extension of this method a new optical configuration has been proposed by Świłło et al. (2011), allow user simultaneously calculate geometry as well as deformation from a single CCD camera. The proposed method is based on an angled laser line examined element subjected to displacements. Figure 3 shows in detail a schematics of the stationary measurement as well as real experimental equipment. An example of this method in its practical embodiment has been described in detail in research performed by Świłło and Czyżewski (2011), Świłło et al. (2012) and Świłło (2012), where the strain was measured in the hemmed sample in an area of 0.6mm, while maximum deformation covered the area of a width not exceeding 50 μm. In addition, an experimental study of grid pattern limitation is demonstrated on figure 4a. For the specimen with the square pattern the grid shape is unrecognized, so the strain calculation cannot be calculated (figure 4b). Next a grid circle where several objects (ellipses) was recorded and analyzed. A selected circle shows strong grid defects (cracking) that make strain measurement for this case very difficult. In particularly, the circle shape recognition by using image processing due to such deformations could be difficult to predict. Finally, a single line pattern with no visual defect such as broken parts, could be easily recognized and analyzed in case of hemming strain measurement (figure 4b).

3.2. Surface quality measurement

Another parameter previously proposed by Swillo et al. (2006) is used to judge a surface quality for hemming process evaluation. The common practise of optimizing assessing of the hemming quality is based on human inspection of the exposed hemmed surfaces. This inconsistency in the quality

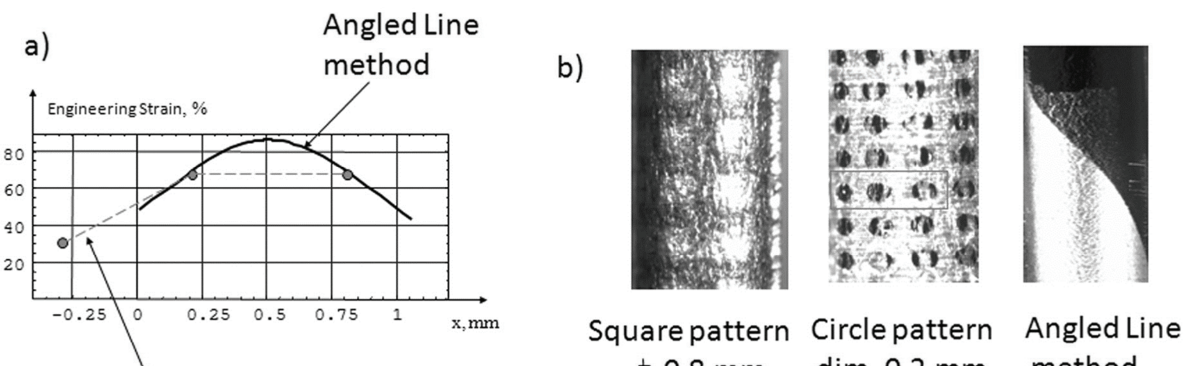

Fig. 4. *Strain measurement for hemming: a) direct results comparison using three results: circle, grid and ALM, b) grid pattern images for three methods of strain measurement.*

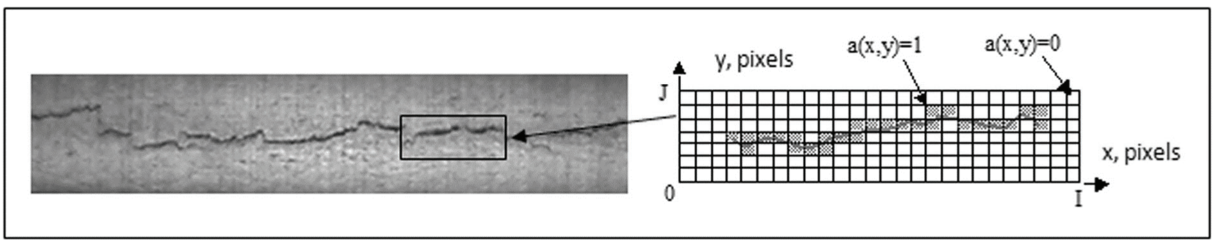

Fig. 5. *Micro-crack formation measurement for the hemmed surface.*

control methodology results in undesirable quality variation in the hemmed parts. Many researchers used various non-optical measurement and image processing methods to study and describe fractures and cracking (Epstein, 1993). The first reported application of the vision method for fracture analysis was by McNeill et al. (1987). Since then many variations of this approach have been developed and implemented to determine crack length or displacement field in the region around the crack, (Livatyali et al., 2004).

local maximum in the graph proves that the maximum number of micro-cracks has been formed and their fusion has started taking place. This means that there has been the localisation of deformation, which favours rather fusion of the micro-cracks already existing than the formation of new ones. As a crack formation index, the average length of micro-cracks relevant to the described maximum has been adopted.

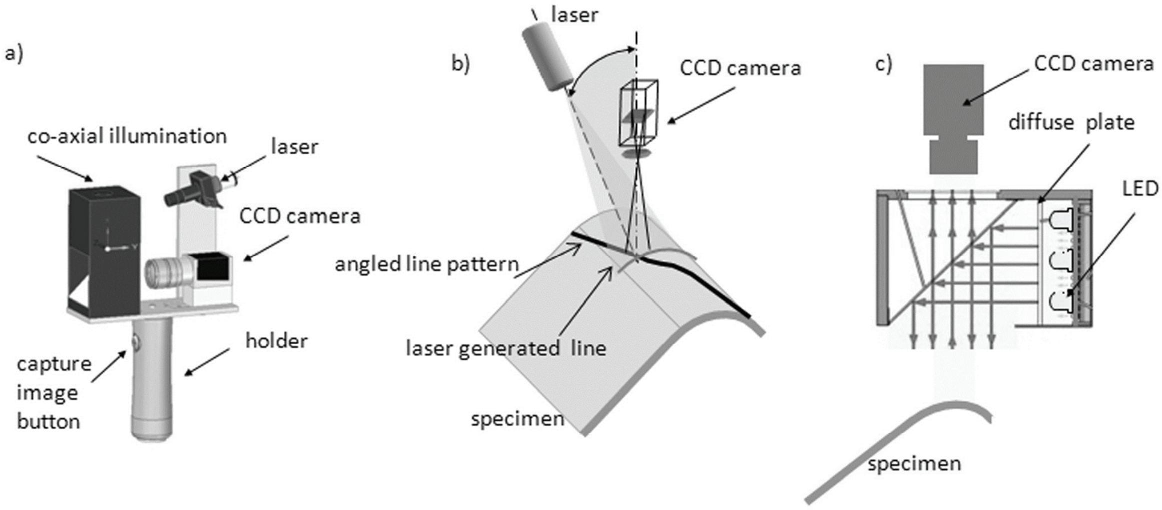

Fig. 6. *Methodology for the measurement using hand-held vision system: a) schematics of the system, b) profile and strain measurement, c) surface inspection.*

In the hemming process, there is a large strain concentration at the edge of the hemmed surface, conferring considerable roughness to this surface. The size of the roughness is a function of the size of the deformation and changes gradually from the surface smooth to very rough, eventually giving rise to the formation of local cracks. In a perfectly run hemming process, the surface remains smooth. In practice, the commonly used method for the surface quality assessment is a visually adopted roughness reference level at which the product should be rejected. This method of elimination leads to a lack of regularity and repeatability in the process of product elimination. The lack of objectivity is a fundamental error, and ultimately has an impact on the whole process of elimination. Therefore, it was necessary to propose an alternative route based on vision control. The proposed method of image analysis of the hemmed surface takes into account the deformation mechanism through statistical analysis of the micro-crack formation (figure 5). To find a quantitative criterion of the surface deformation, the cumulative length of micro-cracks is determined and referred to the number of these micro-cracks. The occurrence of

4. PORTABLE MEASUREMENT SYSTEM

As a final result of the research investigation in the area of the hemming process analysis, a portable, hand-held vision-based measurement system has been developed (figure 6a). The portable vision system is applicable in the analysis of the surface edge hemming under production conditions. All the three above described techniques have been implemented, i.e. surface inspection, geometry reconstruction and strain measurement. First, in the developed technique of scanning along the edge of the inspected part, a manual capturing of the images takes place to provide information on the hemmed surface shape. For that reason, the laser line generator is located on the top of the portable system rotated relative to the camera by a specifically selected angle. Figure 6b shows the result of profile calculation for an arbitrarily chosen location within hemmed surface. Second, using the portable vision system with data on the average length of micro-cracks and crack initiation conditions, we are able–to analyze and characterize the hemming quality for any given material and processing conditions. Figure 6c demonstrates the inspection measurement technique for micro-crack evaluation technique based on the use of co-axial illumination system. The third measurement takes place only in the situation when a simple pattern, i.e. an angled single line, is applied to the sheet surface in the region of the anticipated hemming deformation. To identity that pattern, the, improved by the author, ALM solution based on digital image processing techniques is used to provide more reliable solution, more accurate strain measurements and full automation. To summarize the whole, figure 6 demonstrates the portable vision measurement system capabilities: (a) the surface quality characterization by micro-cracks evaluation, (b) measurement of the surface geometry with profile, and (c) continuous strain measurement with improved ALM.

5. SUMMARY

In this paper the author presents several solutions that have been developed in the area of the hemming process experimental analysis. Since, the hemming deformation area is concentrated in a small corner area, advanced vision-based methods were applied with key parameters such as: strain, geometry and quality measurement. As a result of using the surface quality evaluation method, the hemming quality could be analyzed and characterized for any given material and processing conditions. Next, a successful result of using the strain measurement method for large deformation continuous (high increment resolution) strain distribution, maximum strain (strain peak localization and value), were computed. Finally, a geometry reconstruction was performed by scanning laser method.

As a final results of the research investigation, a specially design portable vision–based measurement system has been developed to conduct all the experiments instead of a previously used stationary solutions. Currently, the hemming experimental investigation confirms that the surface strain distribution is a major factor including the solution to the problem of hemming diagram representation. By calculating more accurately the strain distribution using a new hand-held system and including the history of deformation, a new model of hemming limit diagram representation can be created.

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APARATURA POMIAROWA DO ANALIZY PROCESU ZAWIJANIA

Streszczenie

Nowy, przenośny system doświadczalny został zaproponowany do analizy procesu zawijania. We wstępie przedstawiono informację o potrzebie wykorzystania systemów wizyjnych w analizie problemów występujących w procesie zawijania. Następnie, przedstawiono konstrukcję narzędzi do realizacji trzystopniowego procesy zawijania. Pośród licznych wizyjnych urządzeń pomiarowych stosowanych do pomiarów i rekonstrukcji 3D elementów zawijanych, zaproponowana została przez autora metoda skanowania. W przedstawionym artykule, odniesiono się do problemów zaproponowanych technik pomiarowych i procesu obróbki obrazu w odniesieniu do przykładów doświadczalnych. Po pierwsze, zapisany obraz próbki jest analizowany pod kątem jej geometrii. W dalszej części, przedstawiono szczegóły odnośnie zaproponowanej nowej metody rekonstrukcji geometrii wraz z pomiarem wartości odkształcenia. Na koniec, przedstawiono, system przenośny kontroli jakości w ujęciu przemysłowym.

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