Modelling and Experimental Analysis of Shear-slitting Process of Light Metal Alloys Using FEM, SPH and Vision- based Methods

Leon Kukielka[1, a)], Lukasz Bohdal[1, b)], Sławomir Świłło[2, c)]
Andrii M. Radchenko[3, d)], Agnieszka Kulakowska[1, e)]

[1]*Department of Mechanical Engineering, Koszalin University of Technology, Poland*
[2]*Faculty of Production Engineering, Warsaw University of Technology*
[3]*National University of Shipbuilding named after admiral Makarov, Ukraine*

[a)]Corresponding author: leon.kukielka@tu.koszalin.pl
[b)] lukasz.bohdal@tu.koszalin.pl,
[c)]s.swillo@wip.pw.edu.pl
[d)]andrad69@mail.ru
[e)]agnieszka.kulakowska@tu.koszalin.pl

Abstract. The paper focuses on the numerical and experimental analysis of physical phenomena occurring during the shear-slitting process of light metal alloys. The application of modern modeling techniques using FEM and less-mesh SPH method is presented. Three-dimensional computer models of the process are developed. Thanks to this, it is possible to include in the analyzes the influence of many technological parameters, so far omitted in literature such as: length of the cutting line and its shape, real dimensions of tools, methods of clamping sheet depending on its length and width. Developed models are used to analysis of residual stresses and strains in sheets during and after process under different conditions. The models have universal features in application to different types of materials, different thicknesses of cut sheets and their dimensions. The developed models are validated with experimental research by using vision-based solutions. The proposed advanced vision-based technology is a modern tool which provide accurate measurement of strip surface shape or deformation (displacement) [4]. In this paper this technology was also used to analysis of quantification of the extent to the edge of the region affected mechanically by slitting.

INTRODUCTION

The cutting process is one of the most widespread methods of manufacturing elements, ensuring very high efficiency and having wide application in the technology of shaping parts in various branches of industry. In cutting process mechanism of material separation is often very hard to accomplish in the production cycle due to the difficulties encountered in precision process parameter settings [1, 2]. The main difficulty at production lines during forming light metal alloys is deformation, twisting, bowing, and defects of the sheared edge of sheets such as burrs and slivers. The accumulation of burrs and slivers on the knife, die and the work piece's sheared edge can result in an unacceptable surface finish and increases scrap. The amount of adjustable process parameters and the fact that the influence of these parameters on the process of cutting of light metal alloys is not fully understood, makes it difficult to control the slitting process. In practice the right setup for the slitters is mostly found by trial and error combined with experience. Therefore, the final product frequently has serious defects and drawbacks, such as large deformation and defects on the sheared edge.

The development of cutting processes creates the necessity to develop and improve the calculation methods of this process. Difficulties related to the strongly nonlinear nature of the cutting process did not allows for a long time to obtain reliable and possibly universal methods of its analysis. Extremely fast in recent years, the development in the theory of continuous centers, the theory of plasticity and numerical methods in mechanics, especially finite element methods, related to the progress of computational systems, created conditions in which it was possible to analyze complex problems of plastic forming. Finite element analysis (FEA) and less-mesh methods for example SPH (Smoothed Particle Hydrodynamics) are a powerful and economical methods that has been used widely for engineering design purpose [3].

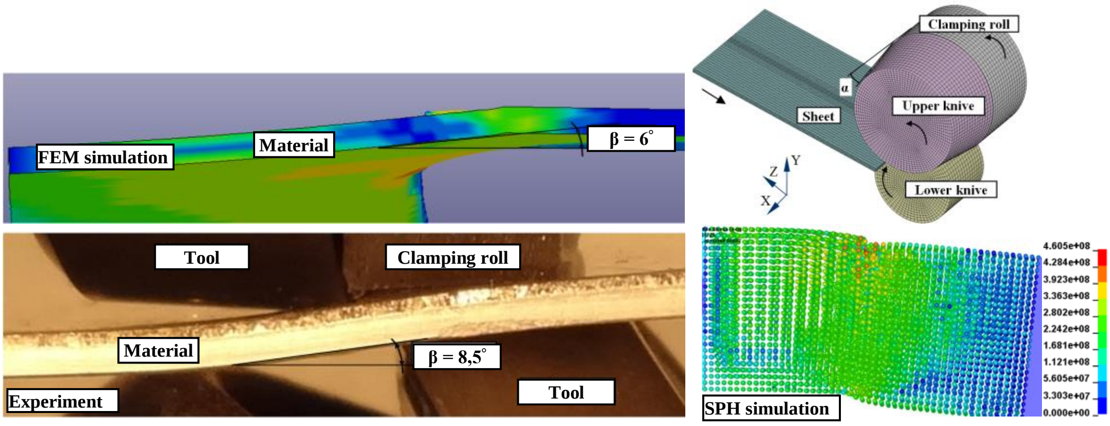
MODELLING OF SHEAR-SLITTING PROCESS AND EXPERIMENTAL RESULTS

The process of shear-slitting is considered as a geometrical and physical boundary and initial value problem, with unknown boundary conditions in the contact area. An updated Lagrange's description is used for the description of non-linear phenomena on a typical incremental step. The increments of strains and stresses are described respectively with an increment of a non-linear strain tensor of green - Lagrange and an increment of the second symmetric stress tensor of Pioli - Kirchhoff respectively. For the purpose of a variational formulation of the incremental equation of the object’s movement for the case of stress cutting, a variational functional is used, in which there occurs only one independent field, namely the field of an increment of displacements. Moreover, it was accepted that compatibility equations are satisfied and the initial and boundary conditions are fulfilled. The mathematical model is supplemented with incremental equations of the object’s motion and the uniqueness conditions. For the purposes of the solution to the present problem, the central difference method, which is also known as the explicit integration method, is used [3].

The modeling of the cutting process using the SPH method proceeds according to the following stages:

- discretization of the domain as a result of which a set of particles is obtained;
- approximation of the kernel (the use of integral representations for the approximation of the function field);
- replacement of kernel approximation by particle approximation;
- approximation of particles at the appropriate time step;
- approximation of particles for each variable in the function space. As a result, a system of ordinary differential equations with a time variable is obtained, which are solved by an explicit iterative method.

Examples of stress distributions in different phases of the process of aluminum alloy AA6111-T4 with a thickness of g = 1 mm are shown in Figure 1. The developed methodology allows for observation of physical phenomena occurring during the cutting process and enables precise determination of areas of adhesion, slip and deformation zone.



(a) (b)

FIGURE 1. Analysis of sheet deformation and residual stresses during cutting process: a) FEM simulation and comparison with experiment recorded by high speed camera, b) scheme of slitting process, SPH simulation, map of equivalent stress [Pa]

REFERENCES

1. H. Wisselink, J. Hue´tink, *3D FEM simulation of stationary metal forming processes with applications to slitting and rolling*, Journal of Materials Processing Technology 148 (2004), pp. 328-341.
2. Sh. Aggarwal, B. Bhushan, N. Katsube, *Three-dimensional finite element analysis of the magnetic tape slitting process*, Journal of Materials Processing Technology 170 (2005), pp. 71-88.
3. L. Bohdal, *The application of the smoothed particle hydrodynamics (SPH) method to the simulation and analysis of blanking process*, Mechanika 22 (5) (2016), pp. 380-387.
4. S. Świłło, *Experimental apparatus for sheet metal hemming analysis,* Computer Methods in Materials Science 13 (2) (2013), pp. 326-332.