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Modelling of guillotine cutting of multi-layered aluminum sheets

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ABSTRACT

The paper presents a numerical modelling of the guillotine cutting process of sheet aluminum bundles. A finite element method with a smoothed particle hydrodynamics approach were coupled to simulate the cutting process. Moreover, arbitrary Lagrangian–Eulerian formulation was also proposed and applied to model the process. Experimental results of the cutting were presented for the validation purposes. The measured force characteristics in all numerical simulations and experiment were compared. The computational costs of the implemented methods were also analyzed. Additionally, a mesh (particles) sensitivity study was performed, and the influence of the mesh on the obtained results was assessed. Based on the outcomes the arbitrary Lagrangian–Eulerian model was selected as more suitable method of modelling the guillotine cutting process and it was validated in different cutting conditions and the influence of technological parameters such as knife velocity and cutting-edge angle was investigated.

1. Introduction

Nowadays, steel, or in general metals processing can be considered as an indispensable part of many industries. Its role in aviation, automotive or military fields is increasing and significant. The forming process of metal sheets can be divided into several operations, which includes slitting, blanking, piercing, trimming and orthogonal cutting. Each of them from the technological point of view has a significant degree of complexity, where shearing is the main cutting mechanism, but ductile fracture is also important. During the process, a very large plastic strain during the cutting operation initiates micro cracks, which subsequently generate macro cracks. An insight into mechanisms which are present during metal processing is crucial from the fundamental and practical point of view. Such knowledge can be gained from experimental tests or numerical modelling, which are today widely available for optimizing and simulating metal processing operations. Recently, numerical and experimental tools have been used to study trimming process. The main aim of the paper by Golovashchenko [1] was to modify the trimming process to eliminate slivers and burrs by looking at the cause of their generation. The main learning was to limit bending of the part being trimmed off and to create a preference for a crack propagation. Hilditch and Hodgson [2] investigated the influence of cutting clearance on rollover and burr behavior of aluminum alloy and magnesium alloy. They concluded that with a larger clearance, the burr height and rollover depth increase. In their other paper [3], it was pointed out that the strain-rate sensitivity is the most important material property to control the distribution of strain in a trimmed sample. The total elongation of trimmed edge of cut sheet is affected by material anisotropy and trimming method according to [4]. Bohdal [5] used smoothed particle hydrodynamics (SPH) method for simulating trimming process, which was monitored using Digital Image Correlation (DIC) technology during the experiment. Thanks to DIC it was possible to quantify material nonlinearities and deformation of material structure.

A large number of papers is devoted to modelling and simulation of orthogonal cutting and machining. One of the first results of cutting modelling were presented in the paper by Marusich and Oritz [6], in which they used Lagrangian Finite Element (FE) model for the orthogonal cutting with continuous and adaptive remeshing implementation. To prevent mesh distortion which accompanies Lagrangian modelling other FE methods can be applied. Olovsson et al. [7] developed a FE code with arbitrary Lagrangian–Eulerian (ALE) formulation to simulate a two-dimensional metal cutting problem. They proved that ALE formulation is numerically effective in such problems, however they pointed out that a constitutive model with a thermal and strain-rate dependency is crucial to obtain reliable results. The effectiveness of ALE

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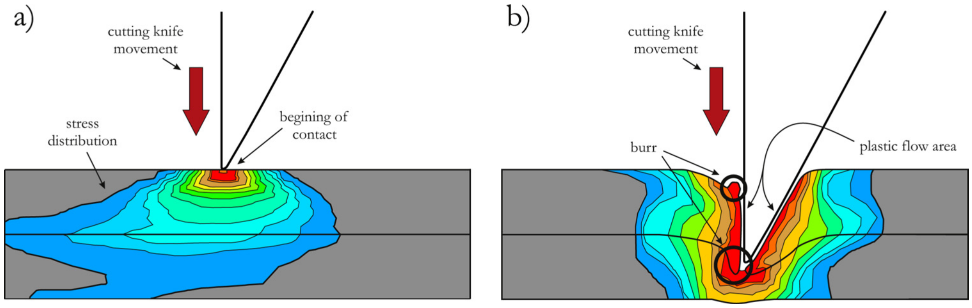

Fig. 1. Schematic of cutting process investigated in study; (a) a knife contacting material, (b) formation of a plastic burr.

formulation in 3D problems was proved by Raczy et al. [8], who modelled deformation of copper during the orthogonal cutting using an Eulerian formulation for the workpiece. Mesh-free methods were also used to simulate problems with high speed cutting, where Madaj and Píškaa [9] investigated how to predict the chip shape and the cutting force using SPH method. In the paper by Limido et al. [10] the advantages of SPH method implemented in LS-Dyna were discussed and the meshless nature of the method with its natural separation possibility was highlighted. However, it was found that the parameters of SPH solver such as initial smoothing length, initial particle density and time step have an effect of the machining variables [11].

Blanking was also investigated using numerical methods and for example in the paper by Husson et al. [12], a new visco-plastic hardening material model coupled with a new damage model was presented and effectively applied in copper sheet blanking FE simulations. The authors confirmed that the proposed constitutive model is suitable to predict blanking process characteristic features. Mao et al. [13] introduced a new discontinuous dot indenter blank holder and they investigated the effect of dot indenter parameters using FE simulations. The parameters were also optimized and applied to the blanking process. As a result, a perfect clean-cut surface was obtained.

In terms of turning metal machining, Duran and Nalbant [14] pointed out the problem of bending of cutting tool. In their paper this bending obtained by finite element method (FEM) was compared with the bending calculated by Castigliano theorem. Saglam et al. [15] investigated an effect of factors, including the entering angle in tool geometry on cutting force components and temperature generated on the tool tip.

As discussed above a standard FEM is widely used in modelling metal processing, however the following steps need to be taken into account to obtain reliable results. Firstly, when using FEM, the material behavior must be correctly modelled including crack initiation and propagation, damage and failure. A proper and validated material data with a suitable constitutive model is vital to obtain reliable numerical results. Moreover, various numerical subroutines such as pre-crack modelling and nodes disconnecting are also available for improving discrete representation of the simulated process. For extremely large deformations and to properly represent the crack propagation during cutting tool-material interactions, a very fine mesh needs to be generated, which can be computational time prohibitive.

Continuously developed numerical methods give a possibility to reduce the discussed above disadvantages, for example, by using mentioned methods including meshless SPH or ALE approaches. Both of them have been used in the past; however, it should be pointed out that in the presented paper SPH and ALE formulations available in LS-Dyna code are applied for modelling and simulation of the dynamic multi-material cutting of several separate aluminum sheets bundles, not a single one as has been done before [1,5,11,14,16,17]. FE modelling is based on the experimental tests carried out using a novel, patented and specially designed laboratory test stand, allowing measurements of forces and applying a vertical, controlled and unique movement of the cutting knife. In the FEM-SPH coupled model, it was decided to account for the metal sheets area within a direct interaction with a knife using the particles, whereas the remaining part is represented by the Lagrangian elements. In the ALE formulation for a selected area where largest deformations were expected, a finer mesh is used, which guarantees correctness of the coupling between the Eulerian and the Lagrangian formulations. Not only the Eulerian domain is remeshed but also the Lagrangian sheet slices. In both cases a selected slice of the aluminum sheets bundle with the knife is taken into account during investigations. Such quantities as deformation, plasticity and force characteristic are also analyzed. Additionally, a parametric study is conducted to verify the influence of the applied mesh (number of particles) on the obtained results. The modelling was compared with the actual tests proved effectiveness of the applied methods and showed good correlation with the experiment. Results obtained are promising in the case of perpendicular cutting.

The paper is organized as follows. In the next section the problem will be introduced and formulated. In Section 3, numerical modelling will be described. Results will be discussed in Section 4. Section 5 consists of final conclusions regarding the presented investigations.

2. Problem formulation

Generally, guillotining is realized with the two straight knives. The upper knife moves downwards with a prescribed velocity, while the lower knife is fixed. Usually, the metal to be cut sheet is clamped on the lower knife. Initially, an interaction between the knife and cutting surface can be described with Hertz contact theory. Subsequently, plasticization of the sheet being cut, and formation of a burr occur. A simple schematic of the described process is presented in Fig. 1, where a sheet is cut progressively due to a small clearance between both the sheets and upper knife.

Principles of operation of the proposed test stand are similar, however, the lower knife is omitted and aluminum sheets are placed on a flat surface. The test stand is installed on a MTS 858 Vertical Tensile Testing Machine. Contrary to an ordinary guillotine where the knife moves under 45 degrees towards the table, on the test stand, here the knife moves vertically downwards and is driven directly by the hydraulic system. During testing a bundle of printing 1100-h12 aluminum sheets (*3 × 30 pcs*) separated every *30^th^* sheet with a cardboard sheet were cut (Fig. 2). A more detailed description of the discussed test stand and experiments can be found in the papers by Gasiorek [18] and Gasiorek et al. [19]. A schematic of the discussed experimental setup is presented in Fig. 3.

3. Numerical modelling

3.1. Model definition

In all simulated cases, it was decided to model only a selected section of the whole bundle of aluminum sheets with appropriate initial boundary conditions. The assumptions for all cases were as follows: