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Shear surface control in blanking by adaptronic systems

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Abstract

Due to the increasing demand of improved geometrical accuracy and reduction of the scattering of mechanical properties in finished products, the need to enhance the active control of dynamic phenomena has become more and more important in the optimization of the blanking processes. The response of the frame to the oscillations arising is strictly dependent on the characteristics of the shock damping systems used and affects the finished shear surface of manufactured parts. In this paper, the application of innovative adaptronic damping systems and the evaluation of their performances are investigated. The developed devices, based on magneto-rheological fluids, allow controllable and reversible changes of damping characteristics during cutting process when an external magnetic field is applied. The experiments, conducted on a hydraulic press using both commercially available hydraulic dampers and magneto-rheological dampers, are presented with particular focus on the excited frequencies and the vibrations to quantify the impact of dynamic phenomena on the quality of final parts. Micro-hardness tests and metallurgical observations were performed to evaluate the quality of shearing surfaces, as well as to correlate the performances of adaptronic devices to the characteristics of the sheared surfaces.

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Keywords: Sheet metal forming; Blanking; Adaptronic; Magneto-rheological; Fractured surface

1. Introduction

Blanking of metal sheets is one of the most frequently used processes in the metal forming industry for the mass production of metal components, both for finished or semi-finished parts. Depending on the process parameters, the material shearing is characterized by complex stresses and strain conditions as demonstrated by Hambli (2001) and

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Lemiale et al. (2009). The generation of new surfaces, with the sudden release of large amount of energy, is often accompanied by heavy vibrations, which affects the press frame, the tooling and, more in general, the overall machine architecture. During and immediately after each shearing operation, considerable frame deflections can be measured, depending on the elastic energy accumulated by the machine as result of the pressure required to cut the material. As soon as the accumulated energy is abruptly released, dynamic vibrational phenomena occur, with detrimental impact on both the machine components and the shape and the quality of the sheared surfaces.

The optimization of the processes and the close respect of tolerances in the final product are strongly influenced by the interactions between the workpiece, the machine and the tools as reported by Breitling et al. (1997) and Guo et al. (1998). Several investigations on shearing processes can be found in scientific and technical literature, focusing on the influence of materials, as in Farzin et al. (2006), the process parameters, as in Fang et al. (2002), and the boundary conditions for the process optimization, as in Stegeman et al. (1999). The quality of the blanking products is affected not only by the material mechanical properties but also by the fracture process in shearing bands between the punch and the die. Brokken et al. (1998) and Klingenberg et al. (2005) studied the fracture propagation and its influence on the fractured surfaces, using finite-element approaches to model the blanking process and correlating the numerical results with the experimental ones to describing the initiation of cracks during the process evolution. Attention to the dynamic phenomena has been given by a reduced number of investigations, such as in Guo et al. (1998) mainly focused on the relationships between the break-through and the press stiffness on the blanking vibrations, and through the development of new control systems, such as the studies of Doege and Seidel (1995) using electronically controlled hydraulic in the force control, the use of servo-controlled presses by Otsu et al. (2003) or the development of damping devices by Murawaka et al. (2001) and Behrens et al. (2005).

The work presented in this paper is part of a research project that aims to develop innovative adaptronic devices for the real-time control of process parameters in sheet metal working operations. The application of innovative devices, based on magneto-rheological fluid technology, on industrial hydraulic presses to control the vibrations arising during sheet metal blanking is presented. After a brief description of the experimental apparatus and the main features of the developed devices, investigations on fractured surfaces by microscope analysis are discussed. Micro-hardness tests and metallurgical observations are performed, in order to evaluate the influence of the different damping systems used on the quality of shearing surfaces, as well as to correlate the performances of magneto-rheological devices to the characteristics of the finished fractured surface of manufactured parts.

2. Control systems for the blanking process

In sheet metal blanking, the typical load-stroke curve may be divided into distinct phases, as shown in Fig. 1.

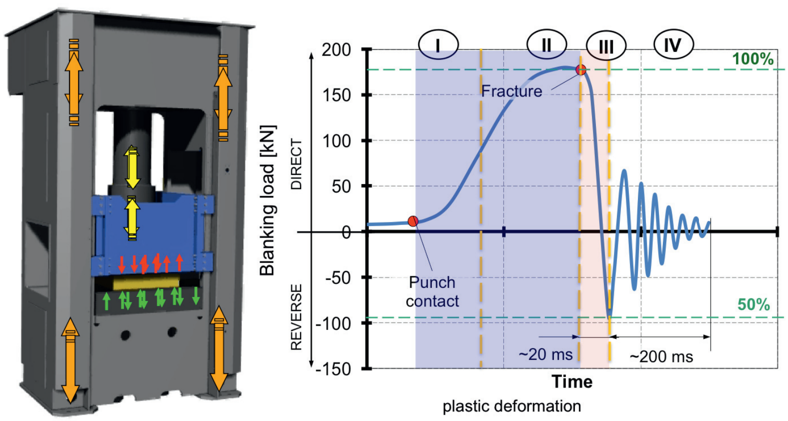

Fig. 1. Reverse load phenomenon in blanking.

The first part (zone I) represents the material deformation, when the punch comes in contact with the metal sheet and starts deforming elastically the blank. The material yield strength is reached in the fibers interested by the material flow along the cutting edges and the plastic shearing deformation occurs. As the pressure increases, the material damage begins and the maximum load value is reached (zone II). When the shear strength of the material in the shearing zone is exceeded, the ductile fracture starts and propagates towards the blank depth (zone III), so that the energy accumulated in the machine frame is released abruptly and the frame snaps back closing beyond its "at rest" position. Regazzo (2010) measured that all the press components, which are designed to work in compression stress state, are suddenly loaded by tensile stresses in a time interval of about 0.02 s. The arising dynamic phenomena determine high loads on the machine and the tooling and, as a consequence, considerable deflections of these components. This undesirable negative load effect is known as reverse load, as defined by Smith (1990) and the consequent shock and vibrations (zone IV) influence the produced part accuracy and the fractured surface quality.

In order to reduce the release rate of elastic energy stored up in the frame machine and, consequently, the impulsive reverse load produced by the crack propagation, in the industrial context several systems for the control of the blanking vibrations can be implemented. The most used are hydraulic systems, which can be divided into (i) hydraulic cushion and (ii) hydraulic dampers. The former provides an upward counter-force through the compression of the oil inside a cylindrical chamber, allowing a good possibility of integration in the blanking bed plate machine. In the latter, the counter pressure, ensured with the contact with the press slide, is generated through control valves that restrict the flow of oil in an external hydraulic power unit out of the cylinder, when it is subjected to an instantaneous velocity increase. Details of the systems were investigated by Regazzo (2010) and by Ghiotti et al. (2010).

3. Experiments

A 2500 kN monolithic double-acting hydraulic press, presented in Fig. 2(a), was used to perform the experiments, where sheet metal parts were sheared between an upper annular punch moving towards a flat die plate at speed punch of 20 mm/s. On the press bed plate, conventional industrial hydraulic cushions and hydraulic dampers were compared with adaptronic shock damping devices, detailed in Ghiotti et al. (2010), showed in the details of Fig. 2(a). In these dampers, based on a single hand architecture, an inner annular orifice of 1 mm has been realized between the outer diameter of the piston rod and the inner diameter of the liner, where LORD MRF-132DG can flowed on flow mode condition at piston displacement. When activated by the electromagnetic field, generated through the electric coils housed in the piston, the fluid increased its local viscosity from free-flowing

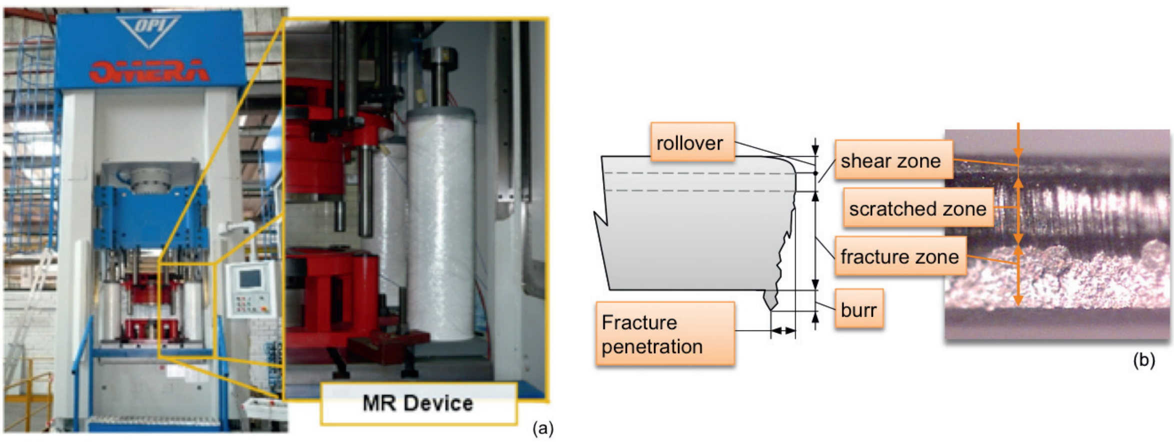

Fig. 2. (a) The 2500 kN hydraulic press on the left; on the right, detail of the magneto-rheological damper; (b) fractured surface edge: rollover, shear zone and fracture zone distinction.

linear viscous liquids to semi-solids, characterized by controllable yield strength, thus allowing a controllable resistance force.

The sheared components were obtained using 2 mm thick AISI 1040 steel sheets. The press ram was moved at a constant speed of 20 mm/s, where in the tooling die set a constant punch-die clearance of 0.2 mm was ensured. The experiments were repeated for four different configurations of the press: with no damping device, with hydraulic cushions, with hydraulic dampers and with magneto-rheological dampers. These last ones were carried out using four levels of current intensity of 2 A. To check the repeatability of results, all the experiments were replicated at least twice.

4. Results

The use of magneto-rheological devices for the damping control during metal blanking allowed a significant reduction on vibration frequencies during the material shearing and the force oscillations, reducing the impact of vibrations for the press structure and the tooling as shown by Ghiotti et al. (2010). Focusing on the quality of the produced blanked parts, the fractured surfaces have been analyzed using a laboratory microscope. As shown in Fig. 2(b), the surfaces under investigations can be divided in characteristic zones results of fracture process: shear zone, scratched zone and fracture zone. Local mechanical investigations on the cut edge surface of the parts have been performed by micro hardness tests, using a Vickers tester device.

4.1. Fractured surface analysis

Fig. 3 compares the fractured surfaces of 2 mm sheets resulting after each blanking process using the damping systems described in §2 and §3. The results, obtained by means of an optical profilometer, show that the sheared surfaces are strongly influenced by the damping devices. As presented in Table 1, the shear zone ranges from 0.23 mm of no damped condition (Fig. 3(a)) to 0.35 mm with the magneto-rheological dampers (Fig. 3(d)). Therefore, with the magneto-rheological dampers the shear zone increases up to 17.7% of the total thickness compared with un-damped condition blanking. Near the shear zone, a “scratched area” can be observed (highlighted in the dotted line): the surface of such area appears scratched and it can be related to the tools vibrations after the material fracture and during the reverse load. When the energy is dissipated as ram vibration, the machine punch scrubbed and scratched at the fracture interface. The larger the vibrations damping, the lower the intensity and the ram oscillations, with a better control of the quality of the sheared surface. The height of the “scratched area” depends on the damping system, and the minimum extension of 25.8% of the sheet thickness is obtained using the magneto-rheological, proving that these systems could reduce the influence of tool vibrations due to the blanking shock, allowing an increase of shear zone compared to the fractured thickness. The surface roughness in the different zones of the fractured edge was measured by ZEISS-TSK Surfcom 1400A profilometer. The average values of roughness (in terms of R_a) of respective several zones for the specimens studied are reported in Table 2. In can be noticed that the lower values in shear and scratch zones are obtained with the magneto-rheological devices.

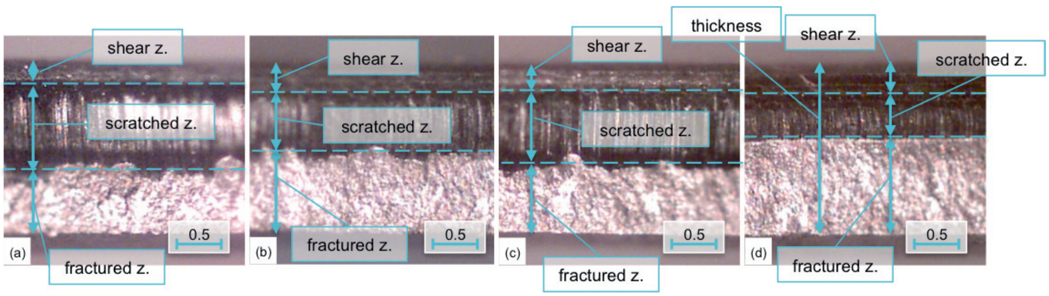

Fig. 3. Images of the cut edge surface: (a) cut edge from no damper condition specimen, (b) cut edge from hydraulic cushion damping (c) cut edge from hydraulic damper damping, (d) cut edge from magneto-rheological devices damping specimen.

Table 1. Width of different zones from sheet blanked specimens.

2 mm sheet	fractured surface [mm]		
	shear	scratched	fracture
No damping	0.23 (±0.06)	0.94 (±0.11)	0.78 (±0.11)
Hydraulic cushion	0.28 (±0.04)	0.58 (±0.09)	1.10 (±0.09)
Hydraulic damper	0.28 (±0.03)	0.70 (±0.05)	0.99 (±0.05)
Magneto-rheological damper	0.35 (±0.03)	0.52 (±0.03)	1.13 (±0.03)

Table 2. R_a roughness values of different zone of the cut edge parts.

2 mm sheet	Roughness Ra [µm]		
	shear	scratched	fracture
No damping	0.06 (±0.05)	1.26 (±0.87)	6.17 (±2.06)
Hydraulic cushion	0.07 (±0.04)	0.34 (±0.23)	5.93 (±3.08)
Hydraulic damper	0.08 (±0.04)	0.74 (±0.56)	7.63 (±2.06)
Magneto-rheological damper	0.06 (±0.02)	0.19 (±0.09)	6.92 (±1.92)

4.2. Micro-hardness tests

The surface hardness of the surface specimens was investigated by micro-hardness tests at the distance equal to 50, 150, 250 and 500 µm from the cut edge (right box of Fig. 4). In all the tested configurations, the surface hardness values decrease when moving from the cut surface towards the centre of the workpiece, see Table 3. At 500 µm distance from the cut surface, the grains are no longer affected by the blanking process, and average hardness results are close to the inner blank value (170 HV).

Table 3. Average micro-hardness of different distance from cut edge parts.

	Average micro hardness [HV]			
	50 µm	150 µm	250 µm	500 µm
No damping	288	248	201	175
Hydraulic cushion	274	247	227	183
Hydraulic damper	245	230	209	172
Magneto-rheological damper	269	234	223	171

The surface hardness increases from the die-roll to the burr side of the part (Fig. 4), where the work-hardening of the material is larger. In the areas closer to the cut edge (at a distance of 50 µm), the Vicker's hardness presents the minimum values with a difference of 119 HV from the maximum values of the un-damped condition. The use of magneto-rheological dampers allows reducing the uncertainty of the surface hardness, with a maximum variation of 62 HV, showing a more accurate control of the fractured surface quality.

5. Conclusions

The paper presents the result of the application of innovative damping magneto-rheological shock dampers, based on magneto-rheological fluids, to control blanking process in sheet metal working operations, focusing on the quality of fractured surface of the produced parts. Experiments were set up to investigate feasibility and practicability of magneto-rheological dampers and to understand the potential benefits in comparison with conventional dampers. Images of the specimen cut edges have showed that an increase of the shear zone compared to the fractured thickness has been ensured, reducing the influence of tool vibrations due to the blanking shock. A reduction of the hardness scatter with the magneto-rheological dampers was measured, allowing an improvement of the control of fractured surface quality.

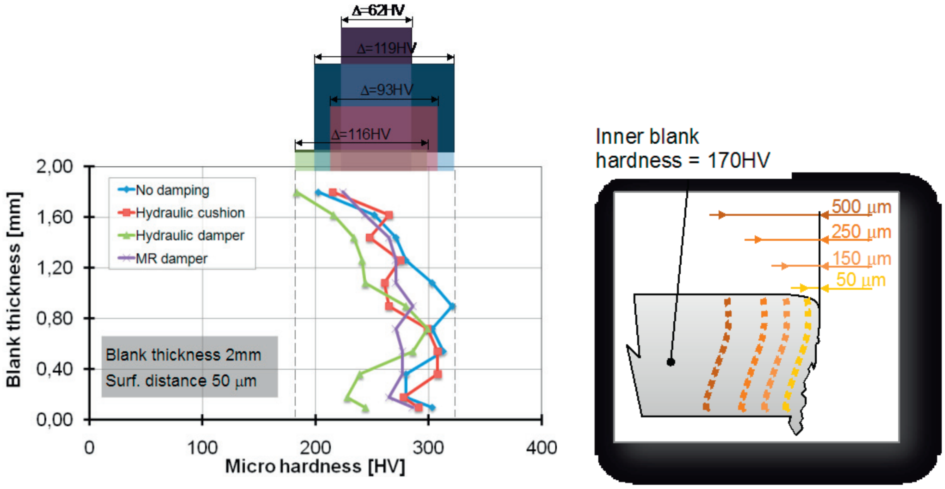

Fig.4. Micro-hardness tests of the cut edge surface. On the right, the investigation paths and the respective distance from the cut edge of specimen are resumed.

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