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RESEARCH ARTICLE

INFLUENCE OF SHEET METAL GRADE AND PROCESS PARAMETERS ON THE SHEAR CUTTING FORCE

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ABSTRACT

This article investigates the parameters that influence shearing cutting forces for three grades of sheet metal materials. A test setup was designed to carry out the cutting experiments. The experimental design implemented takes into account the influence of process parameters (cutting rate and sheet orientation) and geometric parameters (cutting edge radius). The influence of the material type is analyzed through the use of three sheet metal grades. On the one hand, the results show that shearing cutting forces increase proportionally with the material's ultimate tensile strength. Among all the factors studied, the material grade (especially the ultimate tensile strength) has the greatest influence on the shearing cutting force. On the other hand, the tool radius, sheet orientation, and the cutting rate influence the cutting force to a similar extent.

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INTRODUCTION

The ongoing pursuit of reducing automobile fuel consumption has led to improvement in engine performance on the one hand and reductions in vehicle weight on the other. A 15% reduction in fuel consumption is estimated when the vehicle mass is reduced by 25%. To achieve this, new grades of sheet metals known as high-strength steels are used in automotive body manufacturing. Forming these new materials requires significant loading on tooling. These loads can affect tool behavior (Ramdé, 2010). The literature shows that tooling geometric parameters have a significant influence on both the loads experienced and the quality of the produced parts. Understanding the effect of material type on tooling loads and the quality of produced parts is also of major importance for design purposes (Hambli *et al*., 2002; Husson *et al*., 2005; Klingenberg *et al*., 2005; Hatanaka *et al*., 2003; Marouani *et al*., 2009; Gélin *et al*., 2002). The studies presented by (Hambli, 2002; Hambli *et al*., 2002; Husson *et al*., 2005; Bacha *et al*., 2005; Hambli, 2001; Klaasen *et al*., 2006; Khoury *et al*., 2006; Bahloul, 2011) show that among the parameters influencing cutting force and the quality of the final product are: the clearance between the punch and die, tooling geometry, sheet thickness and material type, the friction coefficient, and the cutting speed. In the present work, an experimental design was implemented to study the influence of process parameters (cutting rate and sheet orientation) and geometric parameters (cutting edge radius) on shearing cutting force. The influence of material properties is analyzed through the use of three sheet metal grades.

MATERIALS AND METHODS

Blanking process: Blanking consists of removing material by shearing normal to the sheet plane (possibly not perpendicular to it) (Maillard, 2003). Blanking encompasses several processes. According to (Chabenat *et al*., 1978), these processes include cut-to-length operations, notching, trimming, punching, contour cutting, and shearing. The blanking process makes it possible to produce parts with both closed and open contours. Among the various operations included in blanking, the present study focuses primarily on shearing.

Shearing operation: Shearing is defined as the sliding of metal along a transverse plane between two surfaces without deformation and while remaining parallel to each other. Figure 1illustrates the shearing process (Ismail, 2000).

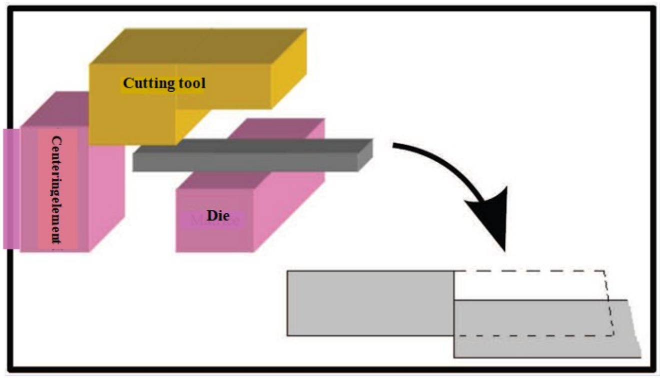

Figure 1- Schematic representation of the shearing process

Sheet metal grade: The raw material consists of sheet metals made from three steel grades. The first grade is cold-rolled mild steel DC04. The second grade is cold-rolled construction steel E220BH, which has undergone bake hardening and is characterized by a higher yield strength and tensile strength than DC04. The third grade is a high-strength steel whose complex microstructure provides an excellent balance between tensile strength and formability. It should be noted that the three sheet metal grades do not have the same thickness.

Where:

R_m: ultimate (maximum) tensile strength
$Rp_{0.2}$: yield strength (0.2% proof stress)
Ag: uniform elongation (before necking)
A: elongation at fracture (total elongation)

Tooling: To characterize blanking forces and analyze their dependence on the above mentioned parameters, an experimental study was carried out. The tests were performed on an instrumented press (BRET 2 MN type). The objective was to conduct shearing tests using a tool geometry configuration corresponding to segments of industrial cutting blades. Based on the geometry of a vehicle door panel, blade segments were extracted for the experimental study. The shearing tests were performed using straight blade geometries, as shown in Figure 2.

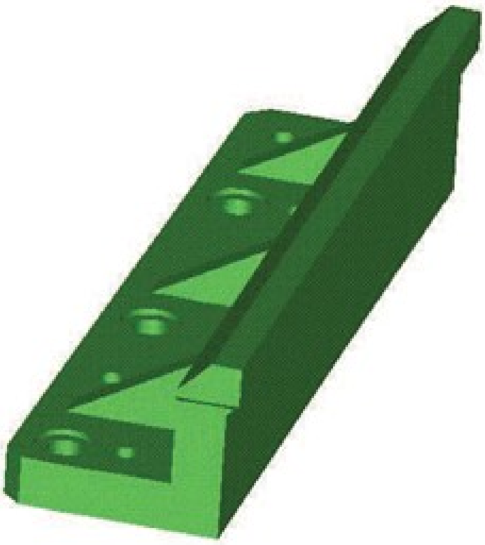

Figure 2. Straightshearing blade geometry

The instrumented BRET 2 MN press (**Error! Reference source not found.**) is a mechanical press with a cutting rate ranging from thirty to eighty strokes per minute. It is a column-type press consisting of a moving part to which the punch and blank holder are attached, and a fixed part supporting the press die.

Figure 3. Press BRET 2 MN

Data acquisition system: To measure the different quantities during the tests, three types of sensors were used:

- **Force sensor:** A Kistler 200 kN sensor, SN1167452, Type 9061 A. The sensor was calibrated on a 25-ton INSTRON tensile testing machine with a preload of 40 kN and a tightening torque of 150 Nm. The relative error of the force sensoris 1%.
- **Punch vertical displacement sensor:** A linear motion transducer, model NR P-40A, modif 0–10 V, SN 1002-19112. The measurementuncertainty of the sensoris 0.01 mm.
- **Punch transverse displacement sensor:** A Keyence laser sensor, model LKG82, SN 690094, with a measurement uncertainty of 0.0002 mm.

The data acquisition unit is a YOKOGAWA DL750 ScopeCorder, Model 701210, SN 91JB20781. The data acquisition software used is CATI.

Expérimental plan: The experimental design was established to analyze the effect of the tool edge radius, sheet orientation, cutting speed, and material grade on shearing forces. The experimental plan is presented in Table 2. Tests were carried out for three sheet metal grades, one tool geometry (straight blades), two cutting edge radii, and three cutting speeds.

Sheetmetalgrades:

- Sheet metal M_1: DC04, thickness 0.67 mm

- Sheet metal M_2: E220BH, thickness 0.7 mm
- Sheet metal M_3: DP500, thickness 0.65 mm

Sheet metal orientation: As a reminder, sheets are generally obtained by rolling. Rolling stretches the material in the direction of passage through the rolls. This deformation creates a structure known as the rolling direction (grain direction) and makes the material orthotropic. In this study, cutting force is analyzed as a function of the angle between the sheet feeding direction during shearing and the rolling direction (grain direction). If the sheet feeding direction is parallel to the rolling direction, the orientation is noted as $S_1 = 0°$. Two other orientation angles are considered: $S_2 = 45°$ and $S_3 = 90°$. Orientation S_3 corresponds to the case where the sheet feeding direction is orthogonal to the grain direction (**Error! Reference source not found.**).

- Orientation S_1= 0°
- Orientation S_2= 45°
- Orientation S_3= 90°

Cutting speed:

Three cutting speeds were considered, corresponding to the machine's operating limits:
- V_1 = 30 strokes/min
- V_2 = 55 strokes/min
- V_3 = 80 strokes/min

Punch edgeradius:
- Radius r_1 = 0.01 mm
- Radius r_2 = 0.05 mm

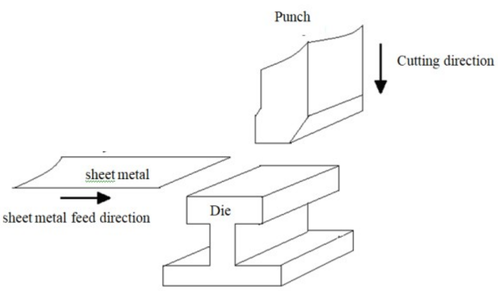

Figure 4. Description of the sheet orientation

RESULTS AND DISCUSSION

Influence of the material grade: The effect of the material on sheet cutting force was studied using three steel grades: DC04, E220BH, and DP500 (Table 1). Since the shearing operation aims to cut the sheet, the ultimate tensile strength R_m was selected as the representative material property. Shearing tests were performed at a cutting speed of V_1 = 30 strokes/min, an orientation of S_1 = 0°, and a punch edge radius of r_1 = 0.01 mm. For each sheet grade, about ten cutting tests were carried out and the average cutting force was calculated.Moreover, since the sheets do not have the same thickness, the average cutting force per material grade was corrected by taking thickness into account. **Error! Reference source not found.** shows the evolution of the average cutting force F_m and the corrected cutting force F_{m_cor} as a function of material grade (R_m). We can notice that the shearing force increases proportionally with the ultimate tensile strength R_m of the sheet materials. This proportionality is clearly observed when thickness is normalized (curve F_{m_cor}).

Effect of cutting speed: The effect of ram speed was studied for stroke rates of 30 strokes/min (minimum press speed), 55

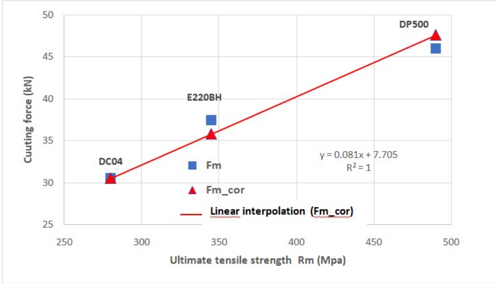

Figure 5. Influence of the material grade

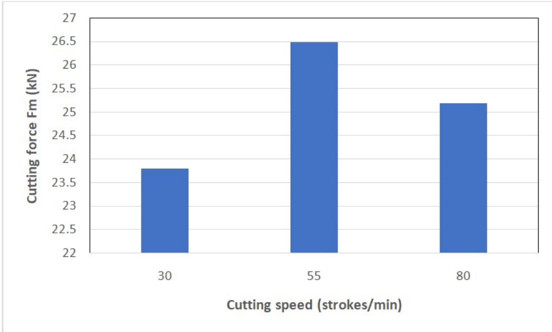

Figure 6. Cutting speed influence on the cutting force

strokes/min, and 80 strokes/min (maximum press speed). DC04 sheet metal was used with a tool edge radius of r_1 = 0.01 mm and an orientation of S_1 = 0°. Between 30 and 55 strokes/min, the shearing force increases from 23.8 kN to 26.5 kN, corresponding to an increase of about 11% (**Error! Reference source not found.**). At 80 strokes/min, the force decreases to 25.2 kN, representing a reduction of about 5% compared to the force at 55 strokes/min, but an increase of about 6% compared to the force at 30 strokes/min. These results therefore suggest that the cutting force follows two different trends within the speed range of the press used in this study. First, the cutting force increases with cutting speed up to a certain point. The force reaches a maximum around 55 strokes/min before decreasing. The minimum cutting force is observed at the lowest cutting speed, and it increases by about 6% when the maximum press speed is reached.

Effetof the sheet metal orientation: Figure 4shows the variation of the shearing force for different sheet orientations. The force is minimal at S_1= 0°, which corresponds to the case where the sheet feeding direction is parallel to the grain direction. The orientation S_2 = 45° exhibits the highest cutting forces. These results suggest that the optimal orientation for lower cutting force is the case where the sheet feeding direction is parallel to the rolling direction.

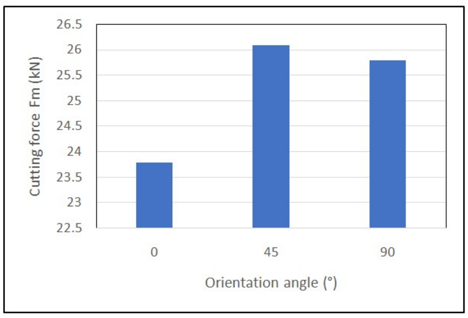

Figure 4. Influence of the orientation angle on the cutting force

Table 1: Material gradecharacteristics

Material		Thickness (mm)	$Rp_{0,2}$ (MPa)	R_m (MPa)	Ag(%)	A(%)
M_1	DC04	0.67	139	280	30	30
M_2	E220BH	0.7	210	345	20	31
M_3	DP500	0.65	320	500	16	21

Table 2. Experimental plan

Configurations	Punchedge radius	Metal grade	Orientation	Speed
1	r_1	M_1	S_1	V_1
	r_1	M_2	S_1	V_1
	r_1	M_3	S_1	V_1
2	r_1	M_1	S_1	V_1
	r_1	M_1	S_2	V_1
	r_1	M_1	S_3	V_1
3	r_1	M_1	S_1	V_1
	r_1	M_1	S_1	V_2
	r_1	M_1	S_1	V_3
4	r_1	M_1	S_1	V_1
	r_2	M_1	S_1	V_1

Effect of the cutting-edge radius: **Error! Reference source not found.** shows the influence of the cutting-edge radius on the cutting force. The cutting force increases with the edge radius. Indeed, when the radius increases from 0.01 mm to 0.05 mm, the cutting force rises from 23.8 kN to 26 kN, corresponding to an increase of approximately 9%.

CONCLUSION

The shearing tests made it possible to study the effects of material grade, process parameters (speed and orientation), and geometric parameters (cutting-edge radius) on cutting forces. It is shown that:

- The ultimate tensile strength of the material is the most influential factor on the shearing force,
- The cutting force increases proportionally with the ultimate tensile strength,
- The results show a non-linear evolution (an increase followed by a decrease) of the cutting force with cutting speed and metal sheet orientation,
- Cutting speed, cutting-edge radius, and sheet orientation influence the cutting force with the same order of magnitude,
- For a given material, the cutting force is minimal for the smallest edge radius, the lowest cutting speed, and when the fiber orientation of the sheet is aligned with the sheet feeding direction.

As a perspective, it would be interesting to analyze the evolution of the cutting force during the shearing cycle. Studying the transient state would make it possible to account for the actual load range, its duration, and consequently, to compare the different cases based on the work performed by the tool (energy consumption).

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