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Influence of the structure of blanked materials upon the blanking quality of copper alloys

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Improving of the productivity of the blanking industry of leadframes (supports for electronic components) involves several research areas. The blanking ability of copper alloys is the topic of this study. In this paper, we propose to determine the influential parameters of blanked materials with respect to the facies of blanked profiles.

For this purpose, the blanking tests on usual copper alloys as well as original alloys, in particular, in terms of microstructure, enabled us to show that the blanking profile was strongly influenced by the mechanical characteristics and the microstructure of the alloys. As a matter of fact, the more work hardened those are (depending upon the making process of the sheet), the larger the fracture zone, is for its own leading to a weaker sheared zone, detrimental as for to the overall blanking quality.

The burr resulting from blanking, it is only conditioned by the microstructure and, in particular, by the precipitates present in the copper matrix. Its formation is not influenced by the rate of work hardening. As for the roll-over zone, it depends mainly on the blanking geometry (punch/die clearance).

Keywords: Blanking profile; Burr; Work hardening; Precipitates

1. Introduction

The industrial making of leadframes (metal supports of electronic components) is obtained through high speed blanking. Metal blanking is performed on thin laminated sheets (0.1–2 mm) at a frequency in the range of 300–800 strokes min^{-1} . The sheets are made of low alloy copper to guarantee the high electrical conductivity ($>4.6 \times 10^7$ S/m) necessary for the functioning of leadframes. The objective of this study is to determine the influence of the blanked material on the quality of blanking, and more exactly the influence of the composition, work hardening and microstructure of the copper alloys on the blanked material part edge and on the quantity of initiated burr.

2. Principle of the tests

2.1. Blanking process of different alloys

In order to compare the influence of the blanked material upon the stamping result, all of the tested alloys were blanked with an industrial progressive precision tool at high speed. The characteristics of the blanking operation are given in Table 1.

The couple blanking punch/die was run in beforehand, by blanking several thousand pieces, because the behaviour of the tools in relation to the blanked material is more selective after wear.

All of the studied copper alloys are listed in Table 2.

2.2. Measurement of the blanking quality

The quality of blanking is expressed by means of the ratio of the different zones of the blanked part edge expressed as a percentage of the whole blanked part edge length: roll-over zone, sheared zone, fracture zone and burr. In this study, the burr is

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Table 1
Blanking parameters

Punch material	Tungsten carbide
Clearance	10 μm
Blanking speed	550 strokes min^{-1}
Work-piece thickness	0.254 mm
Punch dimension (rectangular)	0.5 mm \times 10.5 mm

Table 2
Copper alloys studied (mass%)

Copper alloys	State	Vickers hardness (H_v 200 g)
CuFe2.3P0.03	H12	128 \pm 2
CuFe0.1P0.03	H14	146 \pm 2
CuFe0.1P0.03	H12	124 \pm 2
CuFe0.1P0.03	Annealed	76 \pm 2
CuCo0.28P0.08	H12	126 \pm 2
CuNi0.27P0.01	H12	107 \pm 2
CuNi0.27P0.01	H12*	98 \pm 2
CuAl	H12	99 \pm 2

differentiated from the other zones of the blanked part edge, which, together, form the edge profile, including the roll-over, the sheared and fracture zones.

The final expressed value for each zone is the average of five measurements resulting from five different samples. The uncertainty of this measurement (here set at 2 standard deviations) has been estimated once per type of measurement after 20 tests repeated under the same operating conditions.

2.2.1. Measurement of the blanked part edge profile

Traditionally [1,2], the blanked part edge profile is measured from a perpendicular cut on the blanked plane, thus expressing the different zones of the profile according to their length along the profile under inspection (Fig. 1).

However, to reduce scatter in results, due to the irregularity of the blanked profile, particularly for the sheared and fracture zones and often noticed in the case of copper alloys (Fig. 2), the mean position of the boundary of the different zones of the profile has been measured on a 0.5 mm length by photograph and further image analysis.

In all the tests performed in the present study, the roll-over zone is constant and represents 10% of the thickness of the sheet. Considering the variety of studied alloys and their characteristics (cf. Table 2), what can be deduced from this is that the roll-over zone is, in most cases, conditioned by the punch/die clearance

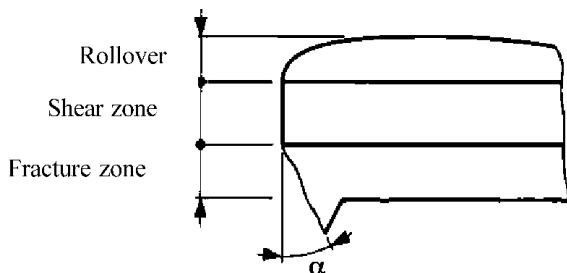


Fig. 1. Traditional blanked profile.

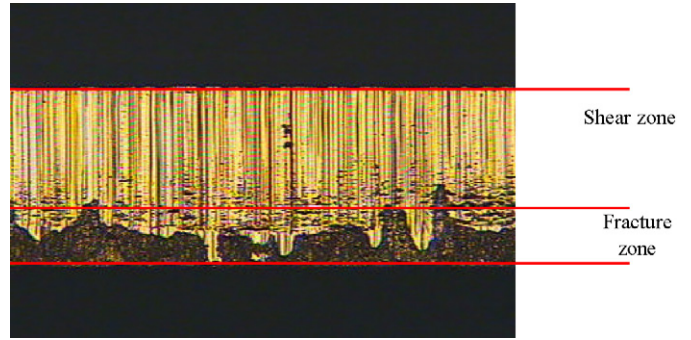


Fig. 2. CuFe0.1P0.03 H14 blanking profile (optical microscope $\times 500$).

[2] and not significantly by the properties of the copper alloy sheets. Some authors, however, have noticed that the roll-over zone increases slightly when the coefficient of work hardening increases [3]. Below, the sheared and fracture zones are regarded as representing 100% of the profile of the blanked part edge.

2.2.2. Measurement of the burr

Blanking is carried out on a progressive tool, consequently, the complex geometry of the leadframe is obtained in several press strokes, which has the effect of crushing the burr (Fig. 3). The burr cannot therefore be measured by its height and its width, as is traditionally done [4].

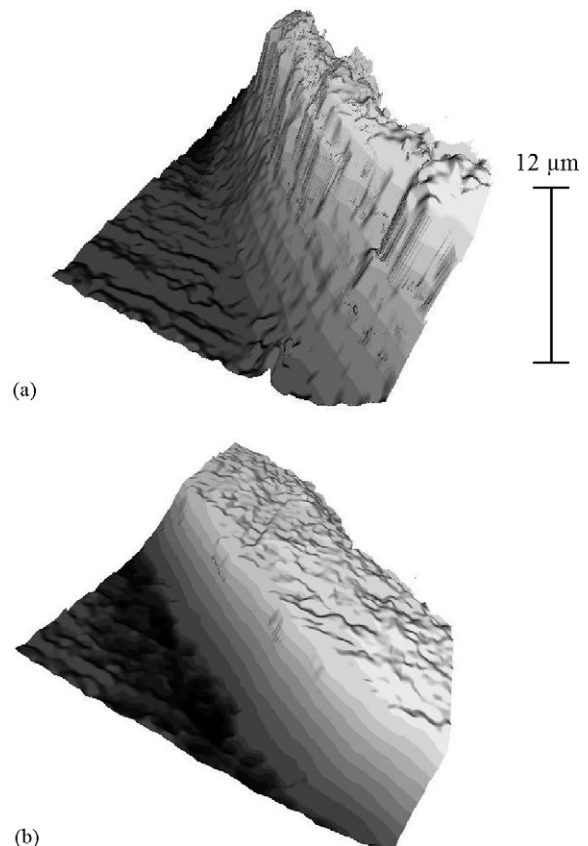


Fig. 3. Burr crushing: (a) blanking burr after one strike and (b) blanking burr in a progressive tool.

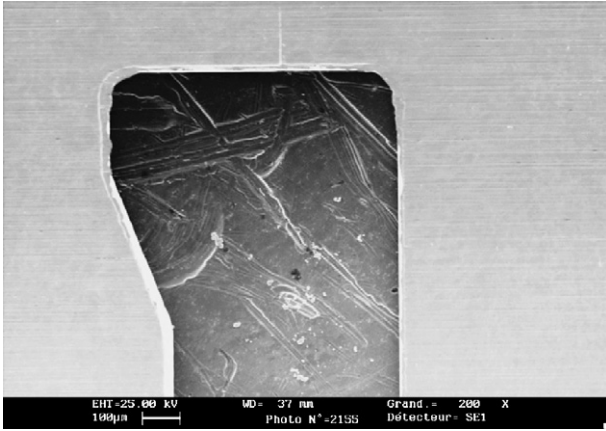


Fig. 4. Illustration of blanked piece.

The quantitative characterization of the burr was therefore performed after undergoing deformation in several stages during the forming process, by means of the image analysis sequence on the scanning electronic microscope (SEM) image (Fig. 4).

However, the volume of the distorted burr can be regarded as being representative of the burr size, since the distortions are mainly plastic (the volume remains therefore constant).

Thus, burr is characterized by its crushed area, the sample lying on a flat plane and the burr being oriented towards the upper side (Fig. 4).

From the SEM photograph, the outline of the area of the flattened burr is drawn “manually” with the aid of dedicated image analysis software (Sigmascan®) which allows the area of this previously defined zone to be calculated.

3. Results and discussion

The results presented in this paper are related to the systematic study of the influence of the composition, microstructure and level of work hardening on the blanking quality of several copper alloys classically used in the manufacturing industry of leadframes.

3.1. Influence of the composition of the sheets

Five copper alloys of different compositions, exhibiting the same state of work hardening H12 (termed half hardened state) were blanked (wt%):

- CuFe2.3P0.03,
- CuFe0.1P0.03,
- CuCo0.28P0.08,
- CuNi0.27P0.01,
- Cu1 (no alloyed copper with 99.9% of copper).

3.1.1. Profile of the blanked part edge

The composition of the copper alloys has a weak influence on the profile of the blanked part edge as shown in Fig. 5. The sheared zone represents, for all the samples studied, 75–82% of

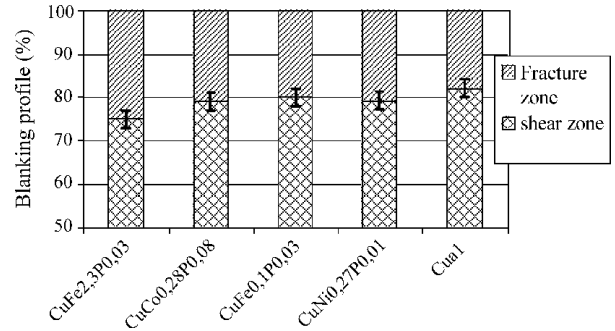


Fig. 5. Blanking profile of copper alloy H12.

the profile. The magnitude of the measuring uncertainty is of 4%.

For all the copper alloys, the material’s work hardening is noticed along the sheared zone of the blanked part edge profile (the first 50–60 μm according to the nature of the alloy), a sign that the strain level is increasing (Fig. 6). At a distance greater than 60 μm from the top surface, hardness becomes constant in the fracture zone since a maximum has been reached, corresponding to the cracking limit. The microhardness values given in the figures are the average of five different tests. The uncertainty is set at 2 standard deviations and results from a set of 20 measurements for each test type.

In contrast, pure copper Cu1 becomes softer during this first stage of plastic deformation, which is characteristic of the material’s dynamic recrystallization phenomenon. This phenomenon is confirmed by the refinement of the copper grains being reduced from 22 to 5 μm in the sheared zone (Fig. 7). It can be assumed that the refinement of the grains brings about an increase in the sheared zone by increasing the ductility of the sheet.

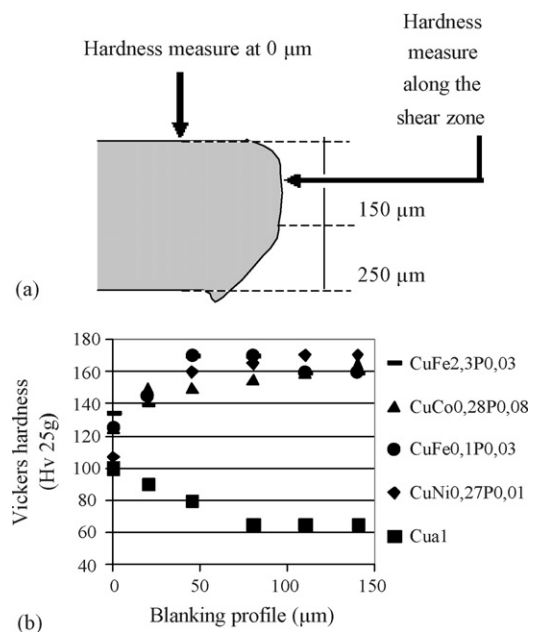


Fig. 6. (a) Principle of hardness measure along the shear zone and (b) hardness of the strip along the shear zone.

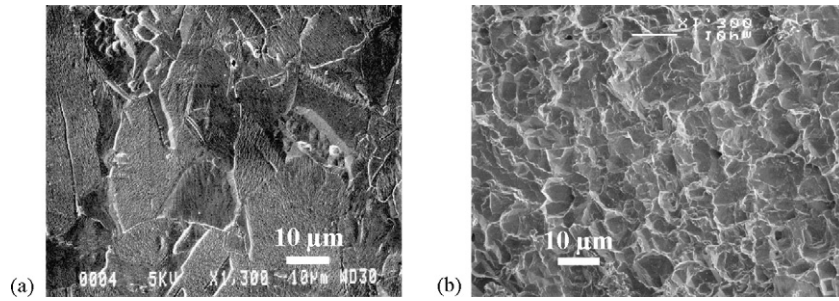


Fig. 7. Microstructure of pure copper CuAl H12 (SEM \times 1300): (a) before blanking and (b) after blanking along the shear zone.

CuAl is not an alloyed copper, its temperature of recrystallization (250 °C for an annealing duration of 30') is therefore lower than that of the other alloys studied in the present paper (400–600 °C).

3.1.2. Blanking burr

The composition of the alloys has a strong influence on the quantity of burr built up during blanking as shown in Fig. 8. The CuFe2.3P0.03 and CuNi0.27P0.01 alloys produce 35% less burr than the CuFe0.1P0.03 alloy.

Two hypotheses are proposed to explain the differences of burr quantity among the tested alloys:

- All of the alloys are in a state of strain H12, however, the alloying elements have a more or less important hardening effect during laminating and blanking. Then the difference of burr would be explained by the different mechanical behaviours.
- The blanked alloys have roughly identical grain sizes (around 10 μ m, except for CuAl with 22 μ m grain size). On the contrary, the alloying elements precipitate mostly into copper. The difference of the nature and morphology of the precipitates can bring about differences in behaviour during the manufacturing process, notably during the burr formation.

3.1.3. Discussion

The choice of the composition of copper alloy has a strong influence on the quality of blanking, even in the case of a small quantity of allowing elements. The influence of the alloying elements is particularly strong upon the quantity of burr formed during blanking which can vary up to 35%. The variations in the blanked part edge profile are smaller than for the burr.

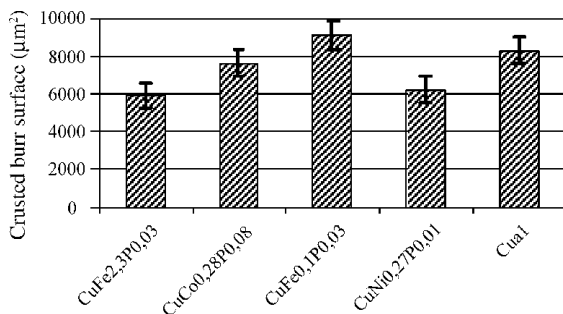


Fig. 8. Crushed burr surface of copper alloys H12.

As a result, the influence of the state of work hardening and the microstructure of the copper alloys on the blanking quality remains to be qualified.

3.2. Influence of the degree of initial work hardening of blanked material

In this part, three alloys CuFe0.1P0.03 in work hardened states H14, H12 and annealed, were blanked. These alloys are of an absolutely similar composition and observation by means of transmission electron (TEM) microscopy has demonstrated the similarity of their microstructure (grain size, precipitation distribution, and nature).

3.2.1. Blanked part edge profile

The profile of the blanked part edge of the CuFe0.1P0.03 is hardly influenced by its state of work hardening (Fig. 9). Taupin et al. [5] noticed the same behaviour for steels of different hardness. The harder the steel was, the more extended the fracture zone was, which must have been linked to reduced toughness. Wong and Das [6] consider that there are two main modes of fracture of the sheets according to the nature of the material:

- If the material is ductile, the blanked part edge profile exhibits an aspect which is almost completely sheared.
- If the material is brittle, cracks will spread suddenly from the beginning of plastic flow and the part edge profile of the blanked sample exhibits an almost completely fractured aspect.

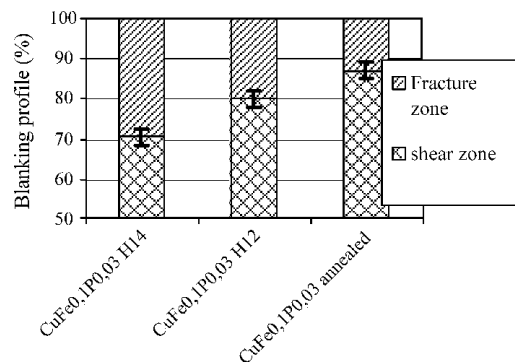


Fig. 9. Blanking profile of CuFe0.1P0.03.

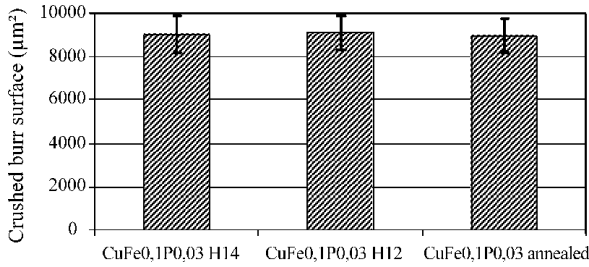


Fig. 10. Crushed burr surface of CuFe0.1P0.03.

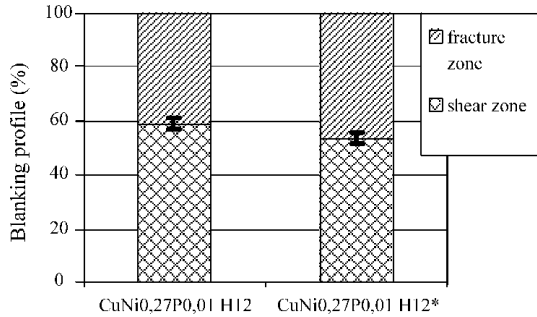


Fig. 11. Influence of precipitates on blanking profile.

The annealed alloy CuFe0.1P0.03 is regarded as being very ductile, while an increasing work hardening level lowers its resilience and extends of the fractured area in the blanked part edge profile.

3.2.2. Blanking burr

The quantity of burr formed during the blanking of the three alloys CuFe0.1P0.03 is identical (Fig. 10). This result demonstrates the independence of the burr with respect to the work hardening. Otherwise, burr growth seems to be independent of the profile, since the latter shows strong variations (fractured zone from 71 to 87%) without affecting the quantity of burr.

3.3. Influence of the microstructure

To study the influence of the microstructure, the results of the blanking of two CuNiP alloys are compared, CuNi0.27P0.01 H12 and CuNi0.27P0.01 H12*, of similar level of work

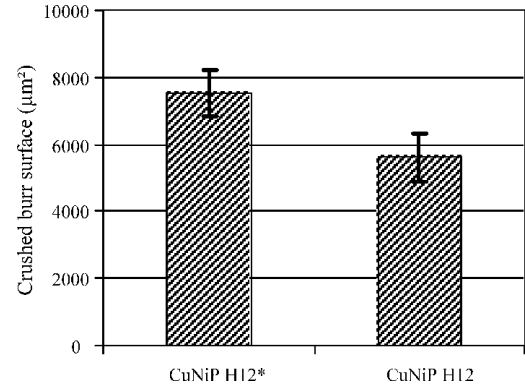


Fig. 13. Crushed burr surface of the alloy CuNi0.27P0.01 H12 and H12*.

hardening, but for which the annealing temperature before rolling is higher than 200 °C limiting the precipitation of hard nickel–phosphorus composites, which can be under the forms Ni₂P, Ni₃P or Ni₅P₂ according to Crampton [7] and Voloshko and Rozenberg [8].

3.3.1. Blanked part edge profile

The CuNi0.27P0.01 H12 alloy gives a rather more fractured zone than the CuNi0.27P0.01 H12* alloy (Fig. 11), while the latter has a lower hardness (cf. Table 2), which contradicts against the previous results of Section 3.2.1. It seems therefore that nickel–phosphorus precipitates favour the ductility of the sheets during blanking.

It can be systematically seen in Fig. 12 that the facies of the fracture zone of the blanked profile contain dimples. However, the number of dimples is smaller in the case of the alloy H12* (Fig. 12), linked to its smaller amount of precipitates. Brokken [9] also compares the precipitation of a second carbide phase in steel with the number of dimples of the fracture zone examined from the blanked part edge profile.

3.3.2. Blanking burr

The quantity of burr is significantly more important in the case of the CuNi0.27P0.01 H12* alloy (Fig. 13), emphasizing the influence of the nickel–phosphorus precipitates.

But can be considered that the nickel–phosphorus precipitates present in the CuNi0.27P0.01 alloy are like so many zones

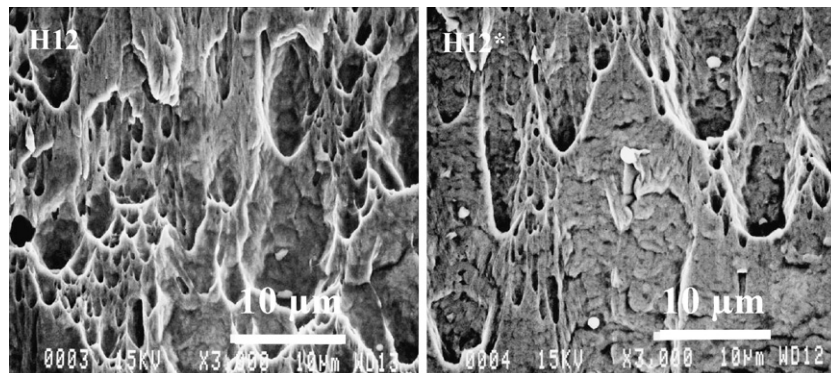


Fig. 12. Variation of the number of dimples on the fracture zone of the alloy CuNi0.27P0.01 H12 and H12*.

of crack initiation during the growth of the fracture zone (cf. number of dimples in Fig. 11) and of the burr. The larger the number of precipitates is the weaker the burr is.

3.3.3. Discussion

It is shown that the level of work hardening of the sheets – during lamination – changes the shape of the blanked part edge profile significantly. In contrast, the level of work hardening does not have any influence on the quantity of burr formed during the blanking process. It appears that precipitates influence the quality of blanking both for the faces of the blanked zone and for the quantity of burr.

4. Conclusion

The quality of sheet metal blanking can be checked by quantifying the relative importance of the roll-over, sheared and fracture zones and burr height. Quality is all the better as the sheared zone is important in the blanked part edge profile, because it respects the desired geometry in the blanking metal process. One can notice that there are noticeable differences in the blanking quality according to the nature of the copper alloy sheet.

Main conclusions are the following:

- The roll-over is hardly influenced by the geometry of the blanking process (blanking punch/die clearance). For the copper alloys under study, the roll-over zone represents, in all cases, 10% of the thickness of the sheet.
- The sheared and fracture zones are mainly influenced by the mechanical properties of the sheet. The more work hardened it is (depending on the technique of sheet making), the greater

the fracture zone is. It can be easily understood that the fracture occurs all the earlier as resilience is weak. Therefore, it leads to a weaker sheared zone, more detrimental to the overall good quality of the blanking process.

- Burr growth is independent of the work hardening state of the sheet, it is hardly influenced, on the contrary, by the precipitates. The CuNi0.27P0.01 alloy for which the precipitation is enhanced sees its quantity of burr diminish by 25%.

N.B.: The uncertainties of measurements correspond to two root mean squares.

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