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COMPARISON OF STAMPABILITY BETWEEN A MICROALLOYED STEEL AND A CARBON-MANGANESE STEEL

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Abstract: Aiming to meet the demand for greater forming capacity while maintaining high levels of mechanical resistance, this study aims to carry out a comparison between the chemical composition, microstructure, mechanical properties and stampability of a Carbon-Manganese steel and a high-strength, low-alloy steel. (ARBL) with a minimum yield limit of 350 MPa, since numerous parts manufactured with this class of steel have high drawing even with hole expansion, as is the case of the part object of this study.

By adjusting the chemical composition and thermomechanical treatment for better stability of mechanical properties and thickness, it was possible to obtain good formability of the microalloyed steel, whose mechanical properties were found to be (resistance limit 472 MPa, yield limit 404 MPa, base elongation 50 of 35% and hardening exponent n of 0.16) and microstructure with grain size 5, globulized non-metallic inclusions type D level 1 and fine series in addition to spheroidized carbides uniformly distributed in the ferritic matrix, whereas Carbon-Manganese steel with resistance limit and similar flow presented comparatively worse results in relation to formability (resistance limit 508 MPa, yield limit 398 MPa, base elongation 50 of 32% and hardening exponent n of 0.12), microstructure with grain size 9, inclusions not elongated metallic type C level 1 fine series and lamellar pearlite fraction which, morphologically, is not the most suitable microstructure for forming processes. In view of the above, the development of the work made it possible to increase the formability of the steel, facilitating the stamping of the studied piece and without the presence of cracks, even in sections of high conformation/hole expansion, as was possible to observe in the comparative photos of the pieces stamped with the steel Carbon-Manganese and Micro alloy designed for better formability.

Keywords: Structural Steels; Carbon-Manganese Steels; Microalloyed Steels (ARBL); Printability; Hole Expansion.

INTRODUCTION

With an increasing demand for flat steels with high mechanical properties and good stampability, in addition to greater dimensional stability of the stamped part, studies and developments of structural steels are necessary, combining efforts both in terms of the steelmaking process and the metallurgical process in order to meet the formability requirements of the part with the minimum possible variation in the thickness and mechanical properties of these steels, making it possible in many cases to reduce the thickness and weight of parts subjected to stress during their use without compromising the safety of the final application, in addition to reducing cost due to weight reduction in the stamped part.

A strong motivation for reducing the weight of automotive parts is the inherent reduction in fuel consumption by reducing the weight of the car as a whole.

Another necessary demand for the sector is the homogeneity of mechanical properties and thickness throughout the coils and batches supplied, since this requirement allows for better stability of the forming process and the dimensions of the parts with minimal adjustments to the tooling used in stamping. the same.

In addition to the technical characteristics demanded by the market, a competitive cost in the steel production process as well as its transformation into pieces with the minimum possible dimensional variation is essential, given the high demand for quality and cost of the market for which the products are intended. printed parts.

GOAL

The objective of the work is to report the process of developing a microalloyed flat steel with specified values of resistance limit of 450 to 570 MPa, yield limit of 350 to 450 MPa, base 5 elongation of 25% minimum and dimensions of 2.5mm thick by 245mm wide applied to a part used in the door locking system of motor vehicles. This steel was classified as LNE355 according to NBR 6656:2016, but with slightly different mechanical properties compared to the public standard as production was originally made with Carbon-Manganese steel.

The project was developed between the Arcelor Mittal and Waelzholz Brasmetal groups responsible for the production and transformation of microalloyed steel, which is supplied in hot-rolled coils with a thickness adjustment process via cold rolling for subsequent transformation into parts through stamping with subsequent zinc coating. with chromate as a passivator, two other players in the automotive chain participated in the improvement project, one of them responsible for shaping and coating the part and the other for assembling it in the door locking system.

PIECE THAT IS THE OBJECT OF THE STUDY

In order to exemplify the product and the finishing conditions in hole expansion sections and above all maintaining the confidentiality of the design dimensions for which this development was directed, below is a photo of the part, which is used in the door locking system of the automotive vehicle. Special attention must be paid to the finishing condition in the hole expansion region.

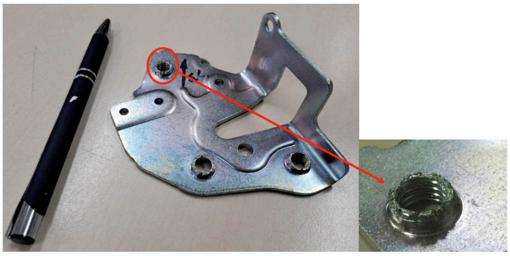


Figure 1: Photo of the part under study, highlighting the cracks present in the hole expansion region.

The main problem that occurs during the stamping of the part under study is the presence of cracks in the hole expansion region, which also compromises the fixation of the screw used during the assembly of the part in the vehicle door locking system.

This anomaly also reduces the useful life of the drill used for thread machining, since the drill is integrated into the stamping tool where the drawing condition directly influences the drill's efforts, generating breakage and premature wear with consequent stoppages of the press for the thread. changing the drill generating greater setup time during the stamping process.

CORRELATION BETWEEN HOLE EXPANSION, MICROSTRUCTURE AND CHEMICAL COMPOSITION

According to Takahashi (1) the desired mechanical properties are determined by the combination of the microstructure of the steels.

Precipitation hardening is widely used for several types of high-strength steel, introducing fine precipitates that can increase the mechanical strength of the steel by 200 to 300 MPa, in addition to contributing to hole expansion, since, during reheating of the plate, before hot rolling, the microalloying elements are easily dissolved in the austenitic matrix.

The main alloying elements used in precipitation hardening of steels are Nb, Ti, Mo and V.

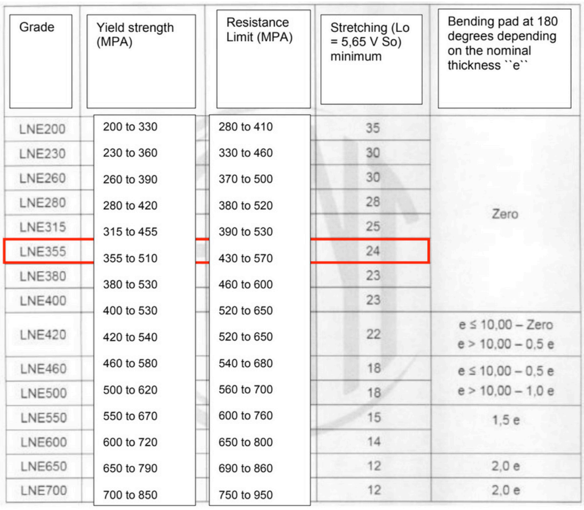
Still according to Takahashi (1), several factors influence the expansion capacity of holes in steel sheets, including the difference in hardness between phases, number of hard phases, C content, elongated inclusions, crystalline texture, index value Lankford “Raverage” and hardening exponent “n”. The greater the uniformity of the microstructure, the greater the hole expandability properties of the material.

It is important to reduce elongated inclusions to a minimum, in addition, it is also necessary to reduce segregation and impurities, since these characteristics interfere with the expandability of holes as they are related to crack nucleation points during the forming process.

CHARACTERISTICS OF THE LNE355 ALLOY ACCORDING TO NBR 6656:2016 (2)

The chemical compositions specified in the standard for the different grades of microalloyed material are given in the Table below, highlighting the steel grade that is the subject of this study:

The mechanical properties specified in the standard for the different grades of microalloyed material are given in the Table below, highlighting the steel grade object of this study, noting that the specification ranges for resistance/yield and elongation limits are slightly different from the standard as it is adaptation to the specification, since the steel originally specified is Carbon-Manganese steel with mechanical properties already mentioned in item 2.



Grade	Yield strength (MPA)	Resistance Limit (MPA)	Stretching (Lo = 5,65 V So) minimum	Bending pad at 180 degrees depending on the nominal thickness ``e``
LNE200	200 to 330	280 to 410	35	Zero
LNE230	230 to 360	330 to 460	30	
LNE260	260 to 390	370 to 500	30	
LNE280	280 to 420	380 to 520	28	
LNE315	315 to 455	390 to 530	25	
LNE355	355 to 510	430 to 570	24	
LNE380	380 to 530	460 to 600	23	
LNE400	400 to 530	520 to 650	23	
LNE420	420 to 540	520 to 650	22	e ≤ 10,00 – Zero e > 10,00 – 0,5 e
LNE460	460 to 580	540 to 680	18	e ≤ 10,00 – 0,5 e e > 10,00 – 1,0 e
LNE500	500 to 620	560 to 700	18	
LNE550	550 to 670	600 to 760	15	1,5 e
LNE600	600 to 720	650 to 800	14	
LNE650	650 to 790	690 to 860	12	2,0 e
LNE700	700 to 850	750 to 950	12	2,0 e

Table 2: Mechanical properties in the direction transverse to the rolling direction for different grades of microalloyed material according to standard NBR 6656:2016. Material object of study was classified as grade LNE355 with different mechanical properties.

MATERIALS

For the study carried out, two different materials were used, one of which was a Carbon Manganese steel (alloy 1) and the other a Microalloyed steel with a process for improved stampability (alloy 2). Chemical composition, mechanical properties, inclusion levels and microstructure of both alloys are reported below:

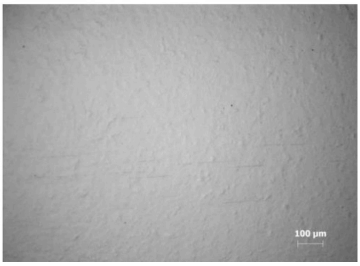
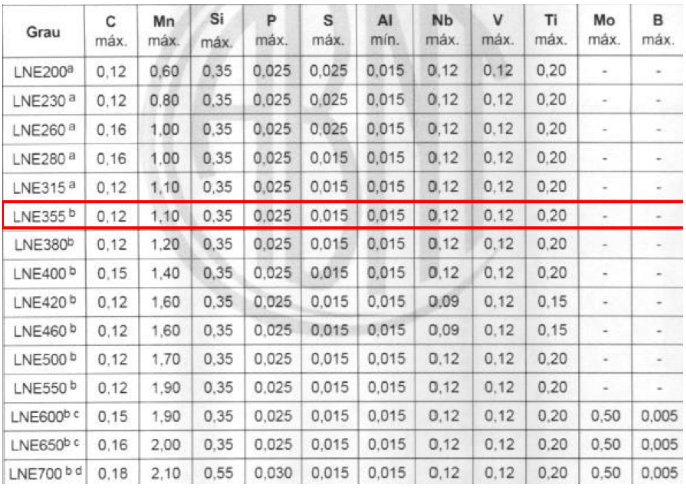


Figure 2: Photo of the microstructure of alloy 1 (C-Mn) with 100x magnification without attack representing the level of C1F inclusions according to the ASTM standard classification (3).



Grau	C máx.	Mn máx.	Si máx.	P máx.	S máx.	Al mín.	Nb máx.	V máx.	Ti máx.	Mo máx.	B máx.
LNE200[a]	0,12	0,60	0,35	0,025	0,025	0,015	0,12	0,12	0,20	-	-
LNE230 [a]	0,12	0,80	0,35	0,025	0,025	0,015	0,12	0,12	0,20	-	-
LNE260 [a]	0,16	1,00	0,35	0,025	0,025	0,015	0,12	0,12	0,20	-	-
LNE280 [a]	0,16	1,00	0,35	0,025	0,015	0,015	0,12	0,12	0,20	-	-
LNE315 [a]	0,12	1,10	0,35	0,025	0,015	0,015	0,12	0,12	0,20	-	-
LNE355 [b]	0,12	1,10	0,35	0,025	0,015	0,015	0,12	0,12	0,20	-	-
LNE380[b]	0,12	1,20	0,35	0,025	0,015	0,015	0,12	0,12	0,20	-	-
LNE400 [b]	0,15	1,40	0,35	0,025	0,015	0,015	0,12	0,12	0,20	-	-
LNE420 [b]	0,12	1,60	0,35	0,025	0,015	0,015	0,09	0,12	0,15	-	-
LNE460 [b]	0,12	1,60	0,35	0,025	0,015	0,015	0,09	0,12	0,15	-	-
LNE500 [b]	0,12	1,70	0,35	0,025	0,015	0,015	0,12	0,12	0,20	-	-
LNE550 [b]	0,12	1,90	0,35	0,025	0,015	0,015	0,12	0,12	0,20	-	-
LNE600[b c]	0,15	1,90	0,35	0,025	0,015	0,015	0,12	0,12	0,20	0,50	0,005
LNE650[b c]	0,16	2,00	0,35	0,025	0,015	0,015	0,12	0,12	0,20	0,50	0,005
LNE700 [b d]	0,18	2,10	0,55	0,030	0,015	0,015	0,12	0,12	0,20	0,50	0,005

a) For grades LNE200, LNE 230, LNE 260, LNE280 and LNE315, the sum of Nb, Ti and V contents must be a maximum of 0.20
b) For grades LNE355, LNE380, LNE400, LNE420, LNE460, LNE500, LNE550, LNE600, LNE650 and LNE700, the sum of the Nb, Ti and V contents must be a maximum of 0.010 and a maximum of 0.22.
c) For grades LN600 and LNE650, the CR content must be a maximum of 0.50%
d) For grade LNE700, the Cr content must be a maximum of 0.60%

Table 1: Chemical composition for different grades of microalloyed material according to NBR 6656:2016.

Material object of study was classified as grade LNE355 with different mechanical properties.

Alloy	C (%)	Mn (%)	Si (%)	P (%)	S (%)	Al (%)	V (%)	Ti (%)	Nb (%)
1 (C-Mn)	0,155	0,76	0,0216	0,0193	0,0116	0,0321	0,0006	0,0001	0,0030
2 (Micro-alloyed)	0,060	0,55	0,0130	0,0200	0,0069	0,0400	0,0010	0,0010	0,0249

Table 3: Chemical composition of alloys 1 – Carbon-Manganese Steel and 2 – Microalloyed Steel (LNE355 with different properties).

Alloy	LR (MPa)	LE (MPa)	Al L05 (%)	Hardening exponent "n"
1 (C-Mn)	508	398	32	0,12
2 (Micro-alloyed)	472	404	35	0,16
Specified	450 a 570	350 a 450	25 mín.	---

Table 4: Mechanical properties of alloys 1 – Carbon-Manganese Steel and 2 – Microalloyed Steel (LNE355 with different properties).

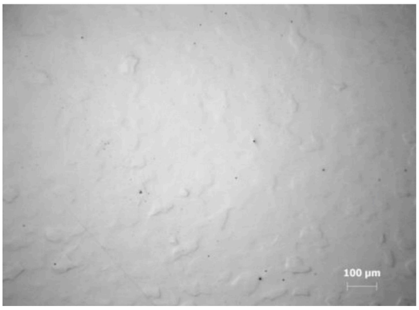


Figure 3: Photo of the microstructure of alloy 2 (Microalloyed) with 100x magnification without attack representing D1F inclusion level according to ASTM classification (3).

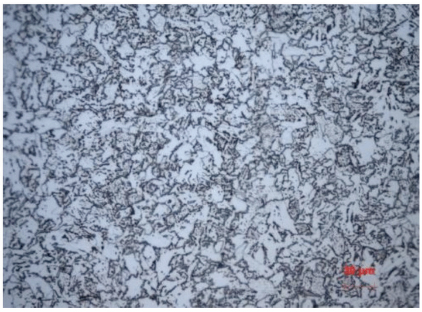


Figure 4: Photo of the microstructure of alloy 1 (C-Mn) with 500x magnification and 3% nital attack (structure composed of ferrite + fine pearlite). Grain size 9 as per ASTM standard (4)

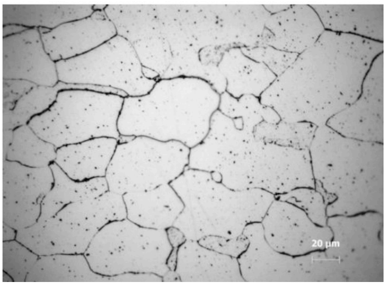


Figure 5: Photo of the microstructure of alloy 2 (Microalloyed) with 500x magnification and 3% nital attack (structure composed of ferrite + spheroidized carbides). Grain size 5 as per ASTM standard (4)

STEEL PROCESS

The increase in the mechanical properties of alloy 1 (C-Mn) occurs mainly due to the addition of the chemical elements Carbon and Manganese, with Carbon being the forming agent of cementite (hard phase present in perlite) in addition to the hardening caused by solid solution together with Manganese and grain refining.

The steelmaking process applied to alloy 2 (Microalloyed) aimed to increase mechanical properties both by solid solution through mainly the addition of the chemical elements Niobium, Carbon and Manganese and by precipitation of carbides through control via thermomechanical process in order to minimize and evenly distribute precipitates that act as barriers to the movement of grain boundaries and dislocations, maximizing the alloy's stampability.

RELAMINATION PROCESS

The material under study referring to alloy 2 (Microalloyed) was acquired by the Waelzholz Brasmetal group in a hot-rolled state with a thickness of 2.60 +/-0.2mm and laminated to meet a thickness range of 2.5 +/-0.12mm.

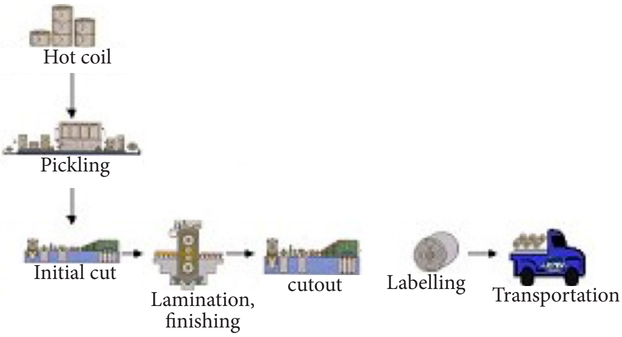


Figure 6: Cold rolling process flow used for the material under study**.**

The cold rolling process applied aimed to reduce the thickness variation in the coil without significantly increasing the mechanical properties of the rolled material. This process was applied with the aim of minimizing the variation of burrs in the hole that will be formed later, since the level of burrs is directly related to the thickness, mechanical properties, microstructure and gap between die/punch in the cutting stage.

The Figure below shows the variation in thickness of the material along the cold rolled roll, excluding the sections at the end of the roll subject to the greatest variation in thickness, it is possible to observe a total variation between 2.45 and 2.49mm.

STAMPING PROCESS

The stamping process used consists of forming the part using a progressive press with thread machining integrated into the stamping tool.

In order to protect the know-how of the company that transforms steel into parts, no information will be disclosed regarding the forming process, design of the part or the number of forming stages.

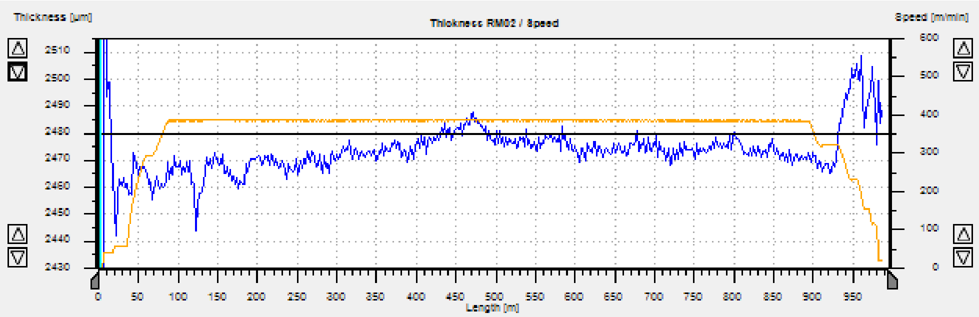


Figure 7: Thickness chart collected after cold rolling process.

METHOD

CHEMICAL COMPOSITION

The chemical composition was carried out in an Optical Emission Spectrophotometer as shown in the Figure below:

Figure 8: Spectrolab Optical Emission Spectrometer.

MECHANICAL PROPERTIES

The mechanical properties were obtained according to NBR 6673:1981 (5). A tensile test specimen was taken perpendicular to the rolling direction for each sample analyzed.

The tests were carried out on a Zwick model Z250 traction machine equipped with hydraulic claws and extensometer.

Figure 9: Zwick Z250 Traction Machine.

OPTICAL MICROSCOPY (MO)

Microstructure analysis was performed on a sample of each alloy. The samples were properly polished and attacked with 3% nital reagent to visualize the microstructure, as shown in the Figure below.

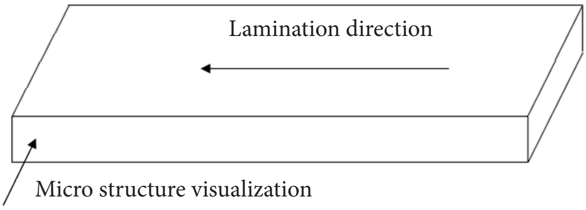


Figure 10: Illustration of sampling to evaluate the microstructure.

The microstructure was checked using a Leica microscope as shown in the figure below:

Figure 11: Leica microscope model DM2700M

RESULTS OF CONFORMATION TESTS

The Figure below shows a comparison between the forming tests of alloys 1 (C-Mn) and 2 (Microalloyed) for the same press and stamping tool configurations.

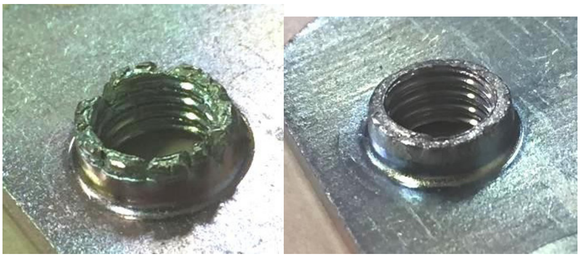


Figure 12: Condition of the drawing of alloy 1 (C-Mn) photo on the left and alloy 2 (Microalloyed) photo on the right.

DISCUSSION

MECHANICAL PROPERTIES

Comparing the results of the mechanical properties in alloys 1 (C-Mn) and 2 (Microalloyed) it was possible to notice a better condition for forming in alloy 2, despite slightly higher yield limit values compared to alloy 1, 404 MPa and 398 MPa respectively. The better formability of alloy 2 is explained mainly based on the elongation and hardening exponent values of alloy 2 (35% and 0.16 respectively), which are significantly better in relation to alloy 1 (32% and 0.12 respectively). Such results explain the better formability of alloy 2 (Microalloyed) compared to alloy 1 (C-Mn).

MICROSTRUCTURE

It is possible to observe that alloy 2 (Microalloyed) presents a level of inclusions D1F (inclusion of globular oxide level 1 fine series according to the comparative table of the ASTM standard (3) and microstructure composed of ferrite + spheroidized carbides uniformly distributed in the ferritic matrix with grain size 5 according to ASTM standard(4).

Alloy 1 has inclusions level C1F (elongated silicate inclusion level 1 fine series according to the comparative table of the ASTM standard (3) and microstructure composed of ferrite + fine pearlite uniformly distributed with grain size 9 according to ASTM standards (4).

By carrying out a comparison of both the level of inclusions and the microstructure of the alloys, it is possible to confirm the better formability of alloy 2 (Microalloyed), since the globulized inclusions and structure with spheroidized precipitates uniformly distributed in the matrix generate a smaller interface area between precipitates of high hardness (carbides and inclusions) and the ferritic matrix of greater ductility, helping the forming and preventing the nucleation and consequent propagation of cracks. Whereas, in alloy 1 (C-Mn), the presence of pearlite and elongated inclusions generate a greater interface area between the hard and brittle precipitates (cementite plaques present in the pearlite and elongated inclusions) and the ferritic matrix nucleating and propagating prematurely cracks during the hole expansion process.

STAMPING PROCESS

For stamping alloys 1 (C-Mn) and 2 (Microalloyed) the same tool was used with the same adjustments for gaps between die/punch, forming speed, lubrication system, hammer pressure and plate press, the differences being found in the forming tests of alloys 1 (C-Mn) and 2 (Microalloyed) exclusively related to the stampability characteristics of each shaped alloy.

CONCLUSIONS

Through the tests conducted, it was possible to conclude that alloy 2 (micro alloy) presented greater stampability compared to alloy 1 (C-Mn). This occurs mainly due to a higher value of the hardening exponent "n" of alloy 2 compared to alloy 1 (0.16 and 0.12 respectively), in addition to a more favorable microstructure for forming present in alloy 2 (globular inclusions with spheroidized carbides and grain size 5), compared to alloy 1 (elongated inclusions with the presence of pearlite and grain size 9).

The cold rolling process applied reduced the thickness variation of the hot rolled material, contributing to better control of the level of burrs in the expanded holes throughout the stamping of the parts, a factor of extreme relevance for the success of the project, since the level of burrs in the holes that will later be formed has a significant influence on the advancement of cracks during the hole expansion process.

The improvement in the forming of the parts with the use of alloy 2 is clear when comparing the photos of the parts stamped with the C-Mn and Microalloyed material present in figure 12. It must be noted that the same forming parameters were used as described in item 9.3.

THANKS

The authors would like to thank the companies Arcelor Mittal and Waelzholz Brasmetal, for providing the equipment and labor that made the development and completion of the project possible.

Special thanks to Messrs. Thomas Frank and Maurício Bomfim for encouraging the development and dissemination of the work developed.

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[3] ASTM E-45:2018 – Standard test methods for determining the inclusion content of steel, p. 7-8

[4] ASTM E-112:2010 – Standard test methods for determining average grain size, p. 1-27

[5] NBR 6673:1981 – Produtos planos de aço – determinação das propriedades mecânicas a tração, p. 1-22.