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FORMABILITY OF STAINLESS SHEET METALS BY DEEP DRAWING - INTEGRAL APPROACH

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ABSTRACT

The paper contains a comprehensive experimental approach to the analysis and solving of problem of stainless steel sheet metals formability at deep drawing. The first phase involves complete investigation of the material (mechanical properties, formability indicators, limit formability curves, tribological properties, structure and, possibly, chemical composition). What follows is a consideration of an actual work-piece: identification of critical zones, types of defects, determining of strain fields, and defining of strain path in limit formability diagram. Investigation and analysis of all obtained results lead to conclusion on solving the problem of formability, and subsequently the necessary parameters of forming process, tools, machines and materials are defined. The procedure was applied on complex geometry work-piece. The work-piece material is austenitic stainless steel sheet metal (AISI 304).
Key words*: deep drawing, formability, stainless steel sheet metal*

1. INTRODUCTION

Deep drawing of thin sheet metals, due to its complexity and, often, insufficient knowledge on particular influential factors, can result in unsuccessfully formed objects. In dependence on how well those factors are mastered, the process can be directed towards the final goal – high-quality pressed part. According to examination of such forming complexes, [1] the following factors are the most important: forming object with its properties, including material, tools, machine, tribological conditions and environment. When products with defects appear, it is necessary to determine the causes of problem and find quality solutions. This paper presents one approach based on complex forming analysis of obtaining pressed part, analysis of material and tribological conditions. Proper analysis of work-piece with defects is particularly important, because all favourable and unfavourable influences which exist in the forming process reflect on it directly. The actual model of pressed piece of non-cylindrical form made of stainless steel sheet metal Č4580 is used (X5CrNi18 9 according to EN 10088, i.e. AISI 304). It is important to emphasize that this material is very important in modern industry, because due to its anticorrosion properties it complies with important development tendencies which are getting more focussed on prolongation of product lifetime and protection of environment.

It is well known that stainless steel sheet metals have worse formability in comparison with classic low-carbon ones. On the other hand, their production and application are constantly increasing. With that in mind, various aspects of obtaining and applying these materials are being investigated [2, 3, 4].

2. INVESTIGATING METHODOLOGY

2.1 Investigation of materials

It is necessary to investigate material thoroughly, which is the first step towards collecting necessary data on actual work-piece. The following mechanical properties are being determined: tensile strength (R_M), yield stress (R_P), elongation at break (A_{80}). Ratio R_P/R_M, ”r” factor and ”n” factor are main formability properties. Specified material is cold rolled sheet metal with more or less prominent plane anisotropy. That is why it is important to determine all previous properties towards rolling, 45° and 90° in relation to that direction. Table 1 gives mechanical and main formability properties defined by standard procedures.

Table 1

Properties of sheet metal Č4580 (X5CrNi18 9, EN 10088; AISI 304) thickness s_0=0,7 mm						
Angle towards rolling direction,°	R_p MPa	R_M MPa	A_{80} %	r	n	R_P/R_M
0	303,2	660,2	30,6	0,824	0,361	0,46
45	308,1	666,4	37,15	1,147	0,35	0,462
90	317,3	630,1	29,5	0,949	0,343	0,5
average value	309,2	655,8	33,6	1,017	0,351	0,471

Chronologically speaking, metallographic investigations of structure and, possibly, chemical composition, can be performed in parallel with previous investigations. This steel belongs to the group of stainless austenite high-alloyed steels and at 200-time magnification flat-axis grains of austenite of equal size can be observed. Inside grain boundaries, matching parts typical for austenite can be seen. The medium for etching of micro sample is royal water in glycerine. The size of grain (according to JUS C.A3.004) satisfies the index G=7-8.

A chemical composition (tab. 2) satisfies standard limits (EN 10088-2 and AISI 304) and it complies with the producer's certificate.

Table 2

Č 4580 (X5CrNi18 9 EN 10088; AISI 304) - Chemical composition, %						
C	**Si**	**Mn**	**Ni**	**Cr**	**S**	**P**
0,04	0,35	1,38	8,51	18,19	0,006	0,021

On the basis of values shown in Tab.1, notably higher values of tensile and yield strength are observed in comparison with low carbon steel sheet metals (with favourable ratio), as well as satisfactory elongation values. High values of strength result in drawing force intensity more than 2 times higher in relation to low carbon sheet metal of same thickness. For these properties, no significant influence of plane anisotropy is observed. The values of n-factor are high, which is favourable considering the formability by stretching. r -factor has low values with very prominent influence of anisotropy in plane. Those values are warning about sheet metal tendency to thinning, which can significantly reduce formability by deep drawing, especially at drawing ratios close to critical ones.

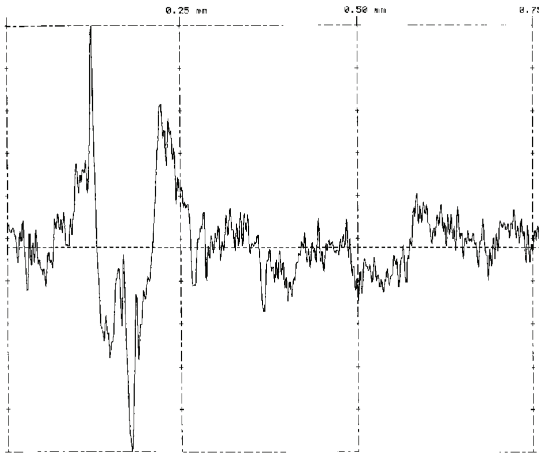

Figure 1 - Surface roughness in the rolling direction

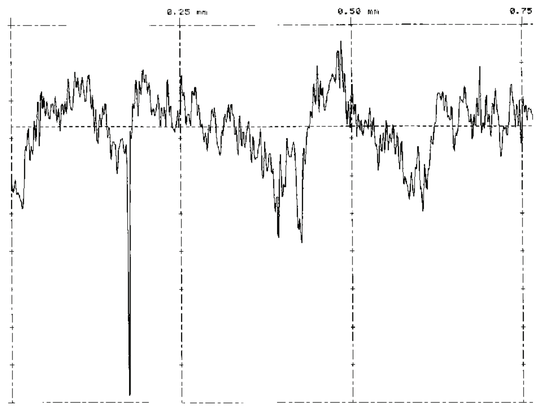

Figure 2 - Surface roughness in the direction 45^o towards rolling direction

Surface roughness was measured (also for three directions in plane) on device Talysurf 6 (TAYLOR HOBSON, England) and it is shown in fig. 1, 2 and 3. Out of many indicators obtained by this measuring, the values of average absolute height R_a, average square height R_q and maximal profile height R_y are given (Tab. 3). The referent length was 0,25 mm, and assessment length was 1,5 mm. If the existing scratches are left out, roughness is relatively equal for all three directions.

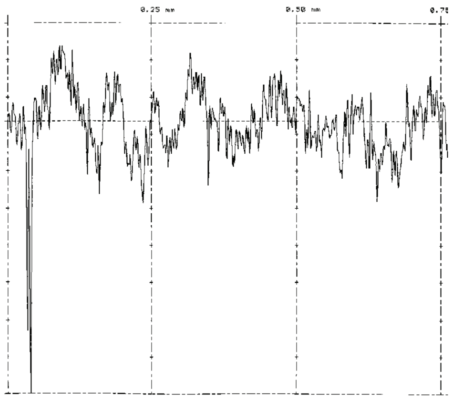

Figure 3 - Surface roughness (direction 90^o towards direction of rolling)

Table 3

Roughness parameters, µm				
Angle	0^o	45^o	90^o	aver. value
R_a	0,035	0,035	0,034	0,0347
R_q	0,052	0,049	0,047	0,0493
R_y	0,570	0,482	0,410	0,4873

2.2 Limit formability

Limit formability diagram (LFD) shown in Figure 5 was determined by classic procedure of stretching the series of test stripes of variable width by semi-spherical punch of 50 mm diameter (Nakazima procedure).

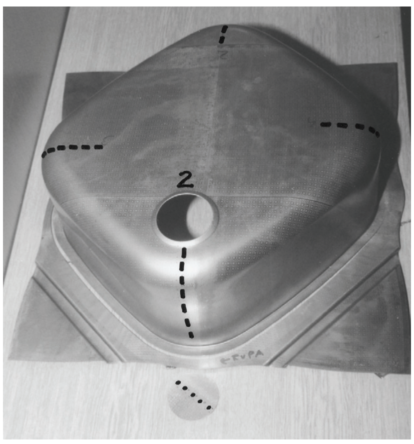

Figure 4 - Form of investigated pressed part

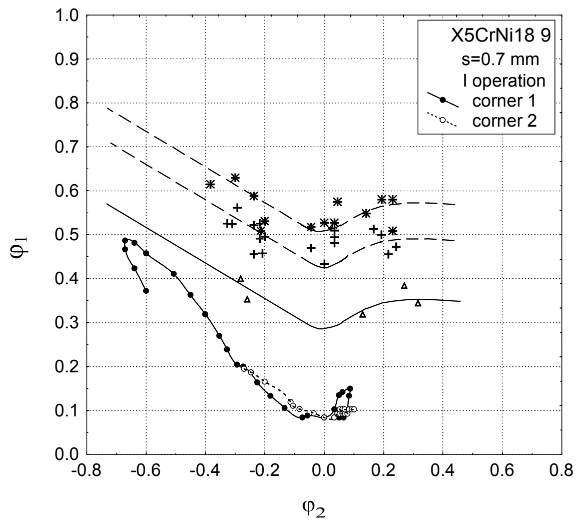

Figure 5 - Limit formability diagram with strain distributions

Dotted lines represent localization curves (bottom curve) and fracture curve (top curve) for measuring grid of 3 mm diameter. On work-piece in Figure .4 (hole at corner 2 has diameter 60 mm) 5 mm grid was applied, so the correction of localization curve position was performed (full line on LFD, fig. 5).

3. RESULTS OF ANALYSIS OF INVESTIGATED PRESSED PART

Identification of types of defects is the first step towards the analysis of defective pressed part. They are most often observed by standard visual inspection. In the actual case, the defects are: the appearance of crack on flat part in rounding zone in one angle, crack in the zone of punched opening and appearance of wrinkles on vertical wall of the part in angular rounding zone. The causes of defects can be established by determining strain distributions in observed critical zones. It is convenient to give distributions in dependence on measuring point (location) of the particular measuring grid element (third main strain perpendicular on sheet metal plane, which shows thinning intensity, is of special importance) and strain in the system of two main strains in plane. More details about presenting and interpreting strain distributions at deep drawing are given in [5] and [6].

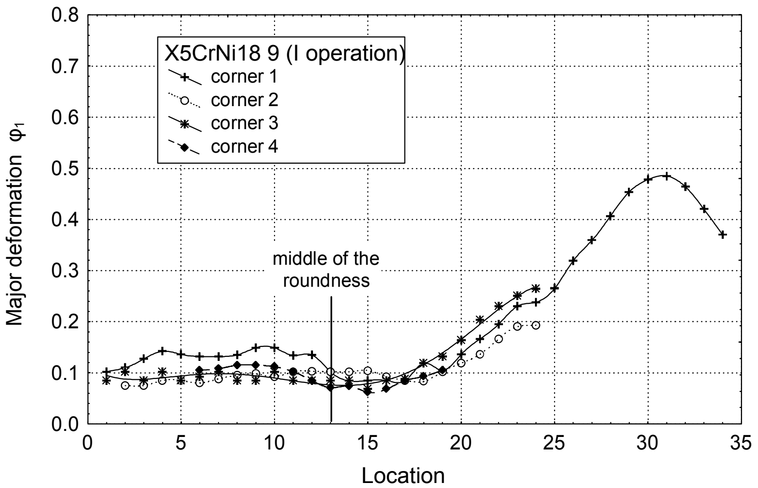

Figure 6 - Larger strain distribution in plane in I operation

Fig.6 shows distribution of first main strain (larger strain in plane) for first operation. Location 1 lies on flat bottom part, and the last one lies on vertical wall of the part. It can be observed that strains in diagonal direction across corner 1 are smaller, which indicates uneven holding of flange, i.e. uneven holding force. Fig.7 shows significant thinning in technologically critical zone in corner 1 around location 10 (distribution curve minimum). That is a potential fracture point. Differences between distributions from one corner to the other confirm the observation that sheet metal retracts into die unevenly, with unbalanced holding force. Fig.4, besides LFD, also gives strain distributions for corners: 2 (with hole) and 1 (opposite corner). From the aspect of danger from localized strain, i.e. fracture in critical zone (around ordinate axis)

forming is relatively safe (relatively large amount of plasticity reserve). Based on this, it can be concluded that drawing ratio is not the cause of defects on work-piece.
Plasticity reserve is satisfactory (fig.8), but fig.9 shows even more prominent unevenness of strains from one corner to the other in relation to situation in fig.7.

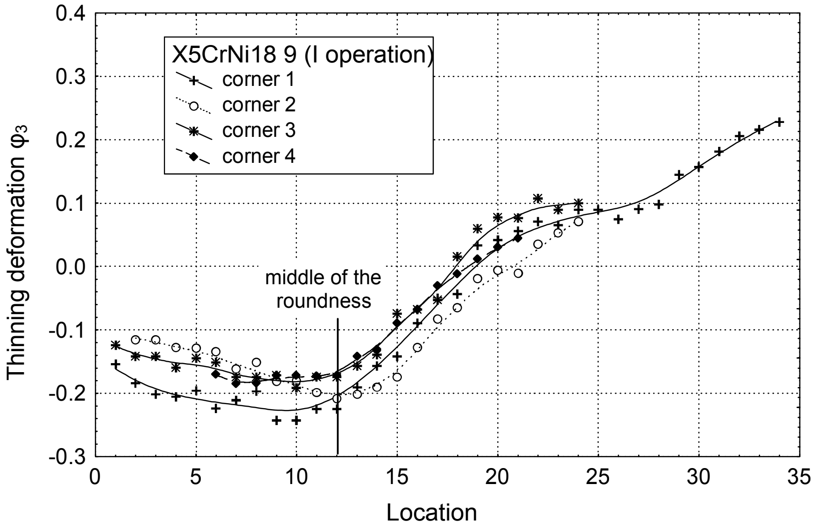

Figure 7 - Thickness strain distribution in I operation

Critical zone is also the edge of hole which bends towards outer side of work-piece, with widening of opening at the end of drawing travel [5]. By observing the edge of punched hole at magnification of up to 100 times, it is possible to evaluate the condition of cutting edges and other tool parameters.

This paper did not include the analysis of tribological conditions [7] at deep drawing of stainless sheet metals, and at this point it should be emphasised that it is necessary to perform strict defining of maximally reduced friction zones (sheet metal holder zone and die rounding with application of quality lubricants, foil etc) and increased friction zone (punch, at least without lubrication, and best with degreased surfaces). The reason for this is the running of process in prominent instability regime (high values of drawing force and holding force with tendency to appearance of wrinkles and drawing instability).

At model investigations, the best results were achieved with specific holder pressure of 6,9 MPa (on pressed part it is consistent with holding force of 1,66 MN) with correct lubrication of flange with quality lubricant.

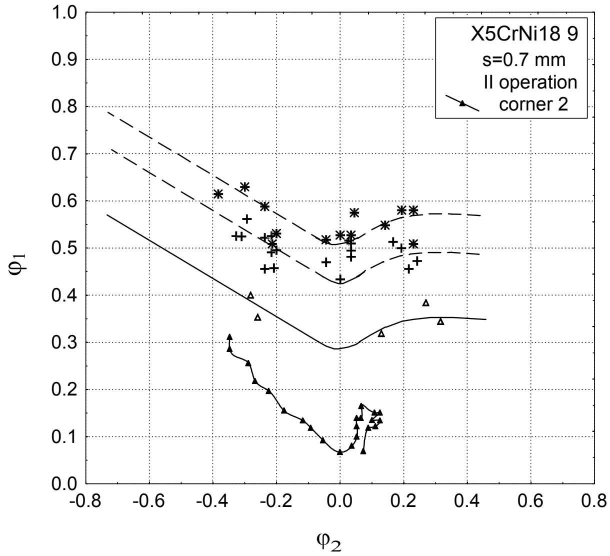

Figure 8 - Strains distribution in LFD for corner 2 in II operation

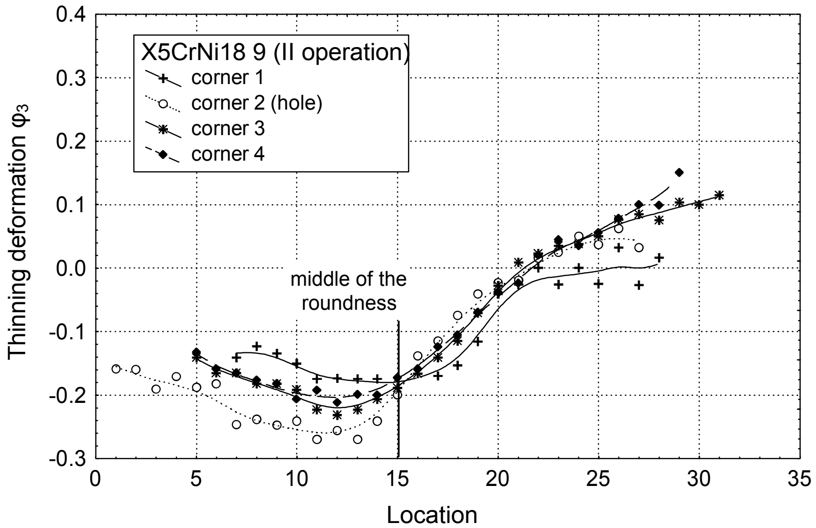

Figure 9 - Thickness strain distribution in II operation

4. CONCLUSION

On the basis of performed investigations it can be concluded that sheet metal of Č4580 (X5CrNi18 9 according EN 10088; AISI 304) represents the material of smaller deep drawing formability in comparison with low carbon car-body sheet metals. It has high strength (more than 2 times higher intensity of forming force of drawing) and high strain at fracture with high value of n-factor, but also low and imbalanced value of r-factor which is manifested as prominent tendency to thinning and appearance of wrinkles. At drawing, the process is inclined to be unstable if some of important factors are disrupted (holding force, tribological conditions etc). That is why quality tools and machine which would provide sufficient and equally distributed holding force on flange are necessary. Non-technological constructive solutions on the work-piece itself must be corrected in case of frequent problems.

On the basis of methodology applied in this investigation, it is possible to identify fully and reliably the important factors which influence the deep drawing process. On the strength of that, the directions for solving potential problems in actual pressed parts are defined.

Designing of technology for deep drawing of stainless sheet metals must be given great attention due to many specific properties (the most important of which have been mentioned in this paper) in relation to classic low carbon sheet metals. In most cases, good knowledge of presented methodology can be used as prevention for avoiding difficulties in manufacturing accompanied by significant costs.

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OBRADIVOST NERĐAJUĆIH LIMOVA DUBOKIM IZVLAČENJEM - INTEGRALNI PRISTUP

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REZIME

Rad sadrži sveobuhvatan eksperimentalni pristup analizi i rešavanju problema deformabilnosti i obradivosti nerđajućih čeličnih limova pri dubokom izvlačenju. Metodika ispitivanja je primenjena na komadu složene necilindične geometrije izrađenom od nerđajućeg austenitnog čeličnog lima (Č4580, X5CrNi18 9 po EN 10088, AISI 304) debljine 0,7 mm.
Prva faza postupka obuhvata kompletno ispitivanje materijala (mehaničke karakteristike, pokazatelji obradivosti, krive granične deformabilnosti, tribološke karakteristike, struktura i eventualno hemijski sastav). Sledi razmatranje konkretnog komada: identifikacija kritičnih zona, tipova defekata, određivanje deformacionih polja i definisanje putanja deformisanja u dijagramu granične deformabilnosti. Sagledavanjem i analizom svih dobijenih rezultata donosi se zaključak o rešavanju problema obradivosti, a zatim definišu potrebni parametri procesa oblikovanja, alata, mašine i materijala.

Nerđajući austenitni čelični limovi imaju znatno lošiju obradivost dubokim izvlačenjem u odnosu na niskougljenične limove. Razlozi su sledeći: niska i neravnomerna vrednost r faktora (s obzirom na ravansku anizotropiju), izvođenje procesa oblikovanja u režimu izražene nestabilnosti (sklonost pojavi nabora i lokalnih pukotina), visoke vrednosti deformacionih sila i odgovarajućih napona, osetljivost na tribološke uticaje itd.

Zbog svega nabrojanog, pri projektovanju tehnologije dubokog izvlačenja nerđajućih austenitnih limova treba biti oprezan. Poznavanjem izložene metodologije, u mnogim slučajevima, preventivno je moguće izbeći teškoće u procesu oblikovanja.