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EXPERIMENTAL RESEARCH IN PILOT PHASES REGARDING THE SEMISOLID STATE PROCESSING OF STEEL

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Abstract

The work presents the results obtained through laboratory stage experiments regarding the semisolid state die forging of steel. The studied steel is submitted to semisolid state die forging in the presence of mechanical vibration with frequencies of 15, 25 and 40 Hz. The use of mechanical vibrations is very important as they play the role of modifying the microstructure and decreasing the quantity of defects. Also through this process the mechanical characteristics of the part are changed.

Key words:

semisolid, steel, die forging, mechanical vibration, frequency, microstructure

1. INTRODUCTION

The early 1970's represents the appearance period of a new material processing technology, currently known as semisolid metal forming (SSF) [1]. This technology was discovered by a student from MIT (Massachusetts Institute of Technology) which obtained for the first time a semisolid suspension with thixotropic characteristics by mechanical stirring [2]. Due to the observed advantages, the researches continued on low melting point alloys. Currently, in the world are many companies which implemented this new technology and commercialized parts, mainly from aluminum and magnesium alloys [3-5]. Simultaneous with the research of the low melting point alloys were studied and the high melting points alloys like steels, cobalt alloys, etc [6].

Semisolid state processing consists in obtaining of a semisolid suspension formed of spherical solid particles included in a liquid matrix. This suspension has a thixotropic behavior i.e. to behave like a fluid when it's agitated and like a gel when it's at rest. The investigations carried out on Sn-15Pb semisolid suspension with the viscometer, showed that the apparent viscosity of the suspension decreases with increasing shearing rate [7]. Hence are resulted the main advantages of this technology namely: improved flow properties, reduced processing forces, obtaining parts in a finished and complex shape, etc. [8]. In the main there are two options for obtaining parts by semisolid state processing namely: rheocasting and thixoforming. If the liquid metal is intensively agitated in the solidification range the dendrites are broken and thus spherical particles are formed which float in the liquid mass. If this semisolid suspension is used to produce parts directly by casting the process is called rheocasting, and if it's used to obtain semi-finished products which are subsequent heated in the semisolid range and used to produce parts, the process is called thixoforming [9]. The methods used to obtain the precursory alloy with globular structure for thixoforming are: electromagnetic stirring, low superheat casting, SIMA method, etc.

The experimental process presented in this paper use mechanical vibration in order to stir the melt. Experiments were conducted on 200-400 steel in order to obtain glass shape parts. Throughout the die forging process the melt was mechanically agitated with an eccentric vibrating motor powered by a frequency converter. Thus the frequency varied in the range 0Hz - 40Hz.

2. EXPERIMENTAL PROCEDURE

2.1. Obtaining the pieces by die forging

Experiments were conducted on the laboratory hydraulic press shown in the photo from Figure 1. The material used for experimentation, 200-400 steel (in correspondence with the OT400 steel, STAS 600-82), has the following chemical composition: 0.18% C, 0.40% Mn, 0.25% Si, 0.011% S, 0016% P, 0.12% Ni, 0.03% Mo. The steel was melted in the 100kg induction furnace. The melt reached to the desired temperature has been cast in to the mold through a chute (Figure 2). The die, the punch, the counter-punch and the chute were lubricated with refractory paint to avoid melt sticking. When the melt in the die reached the semisolid temperature range corresponding to a solid fraction between 40-60%, the punch was lowered and the material took the form of the gap between die and punch.

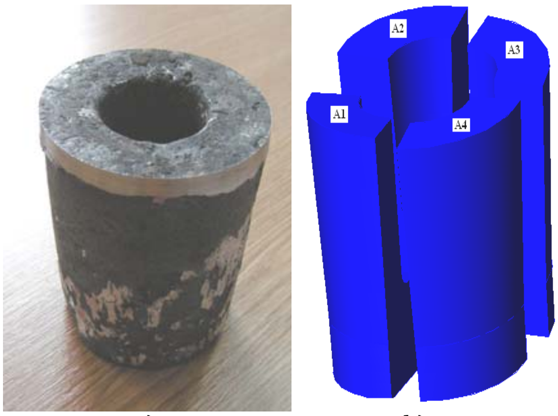
Figure1. Photo of the experimental set-up

Figure2. Casting of the melt in the die

We have obtained four pieces in glass shape through experiments conducted in different conditions given in Table 1. The first piece (denoted A) was obtained without the use of vibrations at a temperature above the liquidus line. The other three pieces (denoted C, D, E) were obtained in a field of mechanical vibration at different frequencies and amplitudes (see Table 1), in the semisolid temperature range. The vibration frequency was changed by supplying the three-phase vibrating engine with a static frequency converter.

Table1. Conditions used for die forging of the pieces

Piece	A	B	C	D
Vibration frequency, f [Hz]	0	15	25	40
Vibration amplitude, a [mm]	0	1	0.7	0.4



a) b)

Figure3. Piece A (a) and the cutting way of the samples notated A1-A4 (b)

The temperature range of the semisolid state processing (40-60% solid fraction, f_s) was determined both by the calculations (based on the Fe-C equilibrium diagram) and by the Thermocalc soft [10]. Due to the small differences between temperature results obtained by calculations and by the Thermocalc soft (1-3 degrees), for further experiments we have considered the processing temperature range of 1504-1514 °C, corresponding to 40-60% f_s.

The piece A (Figure 3, a) was longitudinal cut into four equal parts noted A1, A2, A3, A4 as seeing in Figure 3, b. These samples were used for different analysis as: metallographic observations, impact tests and Brinell hardness tests. For metallographic observations and Brinell hardness tests, A1 and A2 samples were transversal sectioned in pieces of 10 mm size. Samples A3 and A4 as-obtained were used for impact tests.

The pieces B, C and D were sectioned in the same way as the piece A and submitted to the same analysis.

2.2. Sample preparation and analysis details

The sample preparation for microstructure observations was made in accordance with the standard procedure. For preliminary polishing we have used seven different metallographic papers with SiC fine abrasive particles (200, 280, 360, 400, 600, 800 and 1000). The final polishing was made on a felt disk impregnated with alumina suspension (Al_2O_3) of 0.3 μm granulation. Then, the samples were etched with 3% Nital reagent and observed by means of a Kruss optical microscope.

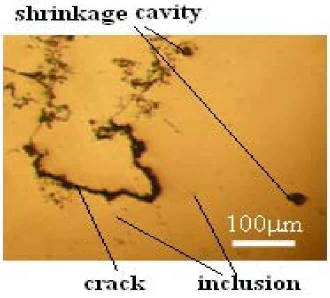
The impact test (at room temperature) was performed on U notch samples. From each piece (denoted A-D) were tested two samples of 55x10x8 mm size. The experimental values represent the arithmetic mean of two tests conducted on each piece.

The Brinell hardness test was performed with a Brinell instrument on three transversal cut samples from each piece, having about 20x20x10 mm size. So, the experimental values represent the arithmetic mean of three tests conducted on each piece. The Brinell ball has 10 mm diameter and the static force applied for 10-15s was of 3000 daN.

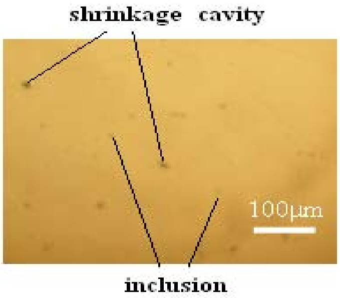
3. RESULTS AND DISCUTIONS

3.1. Microstructural study

The samples were studied with the microscope before and after the 3% Nital etching. On the un-etched samples obtained without mechanical stirring was reveal defects like: shrinkage cavity, cracks and inclusions. A micrograph of this structure is shown in Figure 4, a. The samples obtained by mechanical stirring reveal a reduction of defects quantity, as shown in micrograph from Figure 4, b.



a)

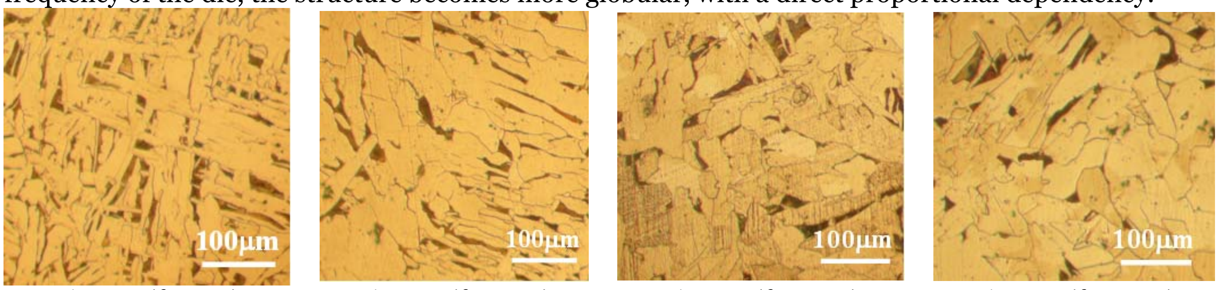


b)

Figure4. Micrographs of the un-etched samples: a) Piece A and b) Piece D

The microstructure of the steel samples consists of ferrite and pearlite, which was revealed after 3% Nital etching (Figure 5). The dark areas represent pearlite and the bright areas represent ferrite. It's also noted that the grain boundary are represented by the thin dark lines. In the micrograph of piece A (see Figure 5) is observed an acicular structure (Widmannstätten), specific to cast steels [11]. This structure is formed due to that, at fast cooling rate it's not possible the complete separation of ferrite at the large austenite grain boundaries. Another feature of this structure is that it has low impact values and percentage elongation, so in generally must be avoided.

Low frequency vibrations, applied to the semisolid melt lead to the formation of spherical particles in the semisolid suspension [12]. It is well known that by mechanical stirring the dendrite arms are broken (which usually are formed by classical casting), thus results solid spherical particles dispersed in the melt [13]. These solid particles represents new crystallization nucleus which lead to obtaining of a semisolid suspension with thixotropic features. As can be seen in Figure 5, there is a difference between piece A and B, C and D pieces obtained by semisolid die casting in the mechanical vibration field. This is because with increasing the vibration frequency of the die, the structure becomes more globular, with a direct proportional dependency.



Piece A (f=0Hz) Piece B (f=15Hz) Piece C (f=25Hz) Piece D (f=40Hz)

Figure5. Micrographs of A, B, C and D pieces, etched with 3% Nital

3.2. Impact and Brinell hardness tests

The variation of the energy absorbed trough tearing (KU) with the die vibration frequency is shown in Figure 6.

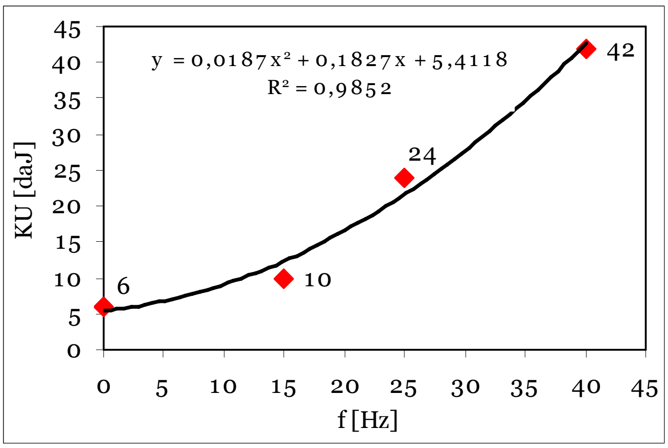


Figure 6. Variation of the energy absorbed trough tearing (KU) with the die vibration frequency (f)

The results show an increase of the energy absorbed trough tearing (KU) with increasing vibration frequency up to 40 Hz. So, due to the application of low frequency mechanical vibration during solidification, the alloy no longer has a typical casting structure, but a globular structure with fewer defects (inclusions, shrinkage cavities). This leads to an increase of the energy absorbed trough tearing. One can see that the highest value of KU corresponds to the highest vibration frequency, i.e. 40 Hz. Hence, the vibration applied during solidification makes the steel to be more tenacious.

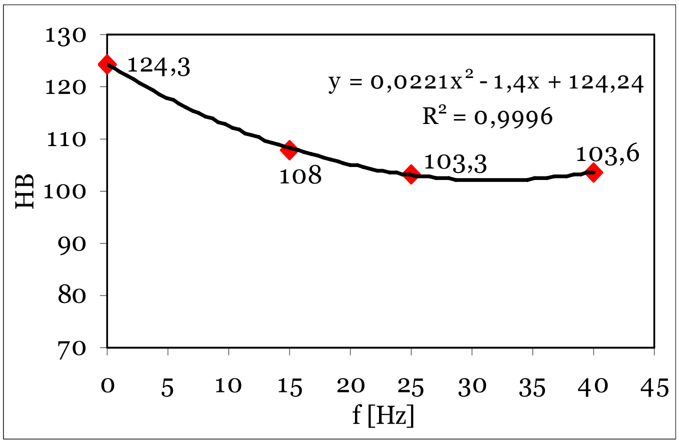


Figure 7. Brinell hardness variation (HB) with the vibration frequency (f) of the die

In Figure 7 is presented the Brinell hardness variation (HB) with the vibration frequency of the die. It is noted a decrease of hardness experimental values with the increase of the vibration frequency. This is because a lamellar structure (obtained in this case by liquid state die forging- Figure 5, piece A) is harder than a globular structure (obtained by semisolid state die forging- Figure 5, piece B, C and D). It may be seen that for vibration frequencies of 25 and 40Hz, the hardness values are approximately the same (about 103 HB). Also, for small vibration frequencies the Brinell hardness have the biggest values.

4. CONCLUSION

The interpretation of the obtained results led to the following conclusions:

- Application of the mechanical vibration of low frequency at semisolid die forging reduces defects as: shrinkage cavity, cracks and inclusions. This improves the quality of the obtained pieces.
- It was remarked that the microstructure of the pieces subjected to mechanical stirring by vibration have a spherical grain structure, which favours the thixotropic behaviour. This feature is best observed in the C and D pieces structure obtained at 25 and 40 Hz frequencies.
- The energy absorbed trough tearing (KU) increases with increasing the vibration frequency for the semisolid die forged pieces compared to those die forged in liquid state.
- It was observed that the Brinell hardness depends on the microstructure features.

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