Study of liquid fraction evolution of semi-solid steels for thixoforming

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ABSTRACT: Major challenge for semi-solid processing includes broadening the range of alloys that can be successfully thixoformed and developing alloys specifically for thixoforming. One important parameter is appropriate solidus-liquidus interval. The wider the solidification interval, the wider the processing window. This study is related to the experimental determination of this critical parameter on eight different steel compositions. This parameter was obtained using Differential Scanning Calorimetry. This technique allows to obtain the solid fraction versus temperature.

Key words: thixoforming, thermophysical properties, liquid fraction

1 INTRODUCTION

Thixoforming – or semi-solid processing – is the shaping of metal components in the semi-solid state. Major challenges for semi-solid processing include broadening the range of alloys that can be successfully thixoformed and developing alloys specifically for thixoforming. For this to be possible, the alloy must have an appreciable melting range and before forming, the microstructure must consist of solid metal spheroids in a liquid matrix. Characterisation of thermophysical properties of semi-solid steels for thixoforming are useful in two ways. First, to study and optimise the behaviour of alloys to be thixoformed and secondly to obtain parameters to be incorporated in numerical models.
A sufficiently expanded solidus-liquidus interval is required which allows the formation of the desired microstructure under variation of temperature and holding time. As suggested by Meuser [1], the most preferable structure is a globulitic solid phase in a liquid matrix with decreasing viscosity during forming. Aluminium and magnesium alloys are the focus of numerous investigations, but research activities concerning the thixoformability of steel alloys have only been commenced recently. As suggested by Atkinson [2], for thixoforming the critical parameters must be as follows :

1) Appropriate solidus-liquidus interval : Pure material and eutectic alloy are not thixoformable for want of a solidification interval. In general, the wider the solidification interval, the wider the processing window for thixoforming. For multi-component systems thermodynamic software is available which allows the calculation of the maximum interval, provided basic data is available.

2) Fraction solid versus temperature : The liquid fraction sensitivity, $(\frac{df_L}{dT})$, defined as the rate of change of the liquid fraction (f_L) with temperature, is a very important parameter for semi-solid forming; it can be obtained experimentally by differential scanning calorimetry (DSC) and predicted by thermodynamic modelling. This would allow some systematic identification of suitable alloying systems.

Kazakov [3] has recently summarised the critical parameters on the DSC curve and the associated fraction liquid versus temperature curve. The critical parameters as suggested by Kazakov are :

• The temperature at which the slurry contains 50 % liquid : T_1.
• The slope of the curve at fraction liquid f_L = 50 % : $dF/dT(T_1)$. To minimize reheating sensitivity this slope should be as flat as possible.
• The temperature of the beginning of melting (T_0).
• The difference ($T_1 - T_0$) determines the kinetics of dendrite spheroidization during reheating.
• The slope of the curve in the region where the solidification process is complete: $dF/dT(T_f)$, where T_f is the temperature of end of melting. In Kazakov's view this should be relatively flat to avoid hot shortness problems.

We studied different alloys named C38 Asco Modif 1, C38 Asco modif 2, 100 Cr6 Asco modif 1 that were modified for thixoforming properties. As pointed out above the main critical parameters for thixoforming must be as follows : appropriate solidus-liquidus interval and fraction solid versus temperature. These two parameters are obtained from Differential Scanning Calorimetry (DSC).

2 RESULTS

2.1 Solidus-Liquidus Interval and Fraction Solid Versus Temperature Characterization

The applicability of a material for processing in the semi-solid state is defined by the solidus-liquidus interval and the development of liquid phase in the interesting temperature range. For the evaluation of the solidus and liquidus temperature a Differential Scanning Calorimetry (DSC) was used. The development of the liquid phase with increasing temperature was calculated using the values from the DSC-measurements. The evaluation of the liquid phase distribution is carried out by the application of a peak partial area integration. The whole area under the enthalpy-area curve is used to determine the melting enthalpy of the material. We admit that the liquid fraction is proportional to the absorbed energy during the transformation. The sample is heated until total melting. Therefore, the liquid fraction can be calculated considering the peak area of the transformation.

Two basic alloys are studied and compared to modified alloys. The basic alloys are C38* and C80*. The modified alloys are C38 Asco modif 1*, C38 Asco modif 2* and 100Cr6 Asco modif 1*. All properties are compared to the base alloy C38. The base alloy C38 was used to study the effect of heating rate on DSC curves. The results are presented hereafter. Figures 1, 3, 5 and 7 show the DSC signal of the melting peak and figures 2, 4, 6 and 8 corresponding liquid fraction.

2.1.1 C38

Referring to [4], the DSC signal and the liquid fraction of C38 are shown in figures 1 and 2. Different heating rates were used (2°/min, 10°/min and 20°/min). The DSC curves show that the DSC signals increase with heating rate but the sensitivity and the peak separation decrease. For liquid fraction evolution, the results are similar for 10 and 20°/min. All subsequent experiments were therefore conducted with a heating rate of 20°/min. During melting of C38 we observed three different peaks which are related to the transformation:

1) $\gamma \rightarrow \gamma$ + liquid,
2) peritectic transformation γ + liquid $\rightarrow \delta$ + liquid, and
3) δ + liquid $\rightarrow$ liquid

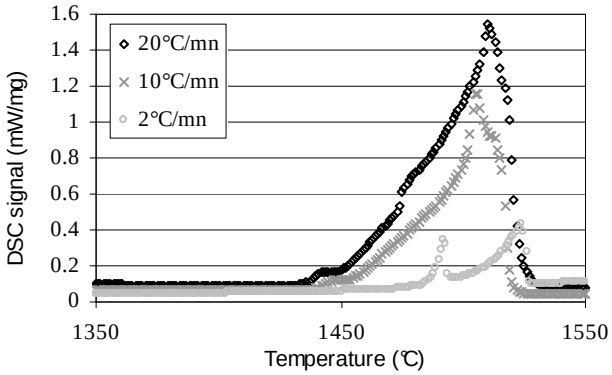

Fig.1. DSC signal of C38

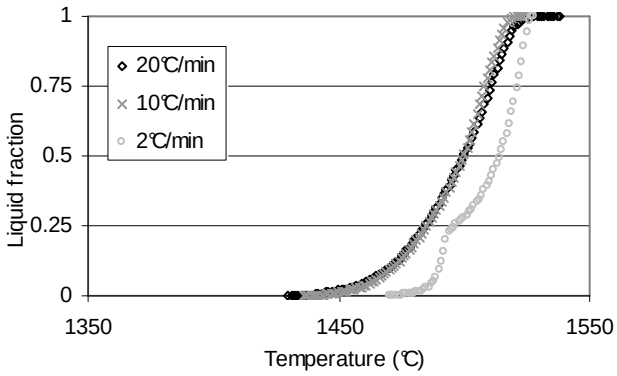

Fig.2. Liquid fraction of C38.

* The composition follows euronorm DIN code. C38 = (carbon 0.38 %), C80 = (carbon 0.80 %), 100 Cr6 = (carbon 1 %, Cr 1.5 %).

2.1.2. C80 and C38

The DSC signal during melting and the liquid fraction of C80 are presented in figures 3 and 4. A comparison with C38 and C80 is also shown.

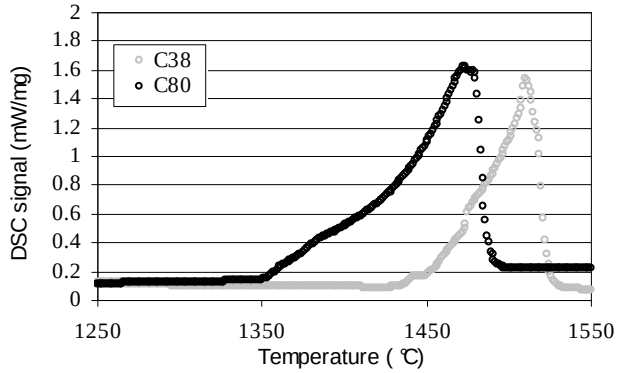

Fig. 3. Comparison of the DSC signal between C38 and C80

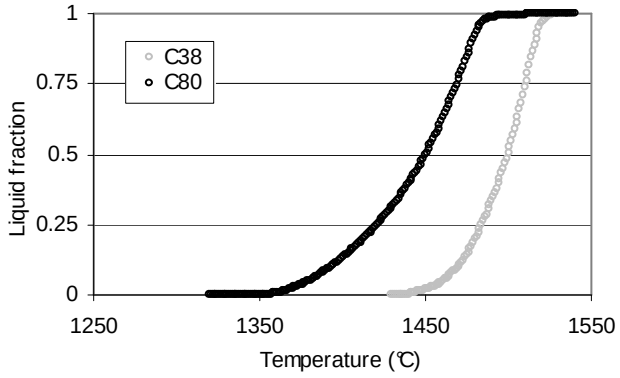

Fig. 4. Comparison of the liquid fraction between C38 and C80

With regard to Kazakov parameters, C80 exhibits better behaviour than C38. The beginning of melting T_0 is lower, T_1 is lower, the solidification interval ($T_f - T_0$) is larger (see table1), and the slope of the curve dF/dT is flatter at T_1 and T_f.

2.1.3. 100Cr6, 100 Cr6 Asco modif 1, C38

The DSC signal of 100 Cr6, 100 Cr6 Asco modif 1 and C38 are shown in figures 5.

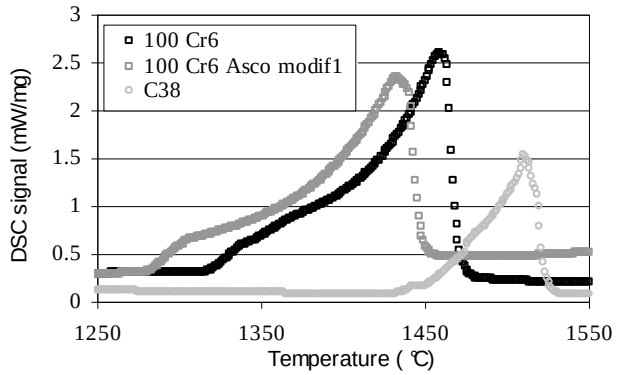

Fig.5. Comparison of the DSC signal between C38, 100 Cr6 and 100 Cr6 Asco modif 1.

The corresponding liquid fractions are shown in figure 6.

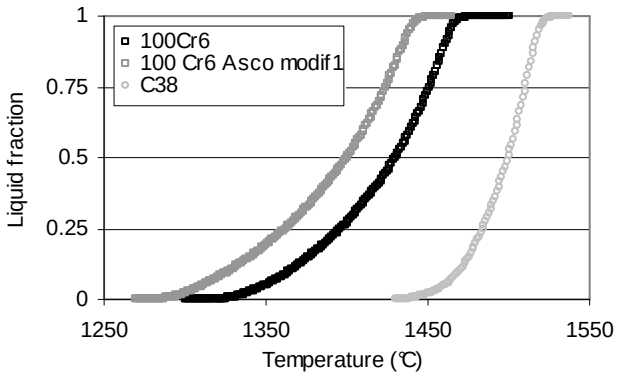

Fig.6. Comparison of the liquid fraction between C38, 100 Cr6 and 100 Cr6 Asco modif 1.

With regard to Kazakov parameters, 100 Cr6 Asco modif 1 exhibits better behaviour than 100 Cr6 and C38 one. The beginning of melting T_0 is lower, T_1 is lower, the solidification interval ($T_f - T_0$) is slightly larger (see table1) and the slope of the curve dF/dT is flatter at T_1.

2.1.4. C38 Asco Modif 1, C38 Asco Modif 2, C38

The C38, C38 Asco modif 1 and 2 results are shown in figures 7 and 8.

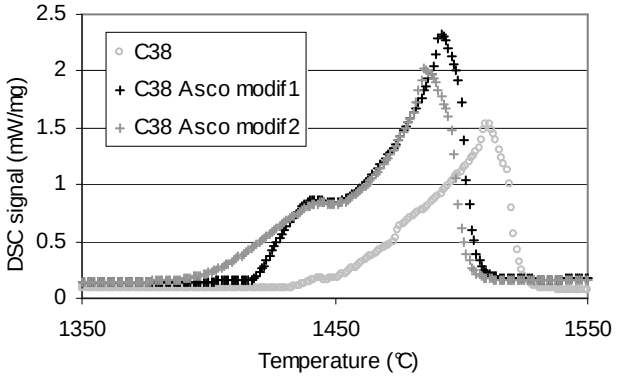

Fig.7. Comparison of the DSC signal between C38, C38 Asco modif 1and C38 Asco modif 2.

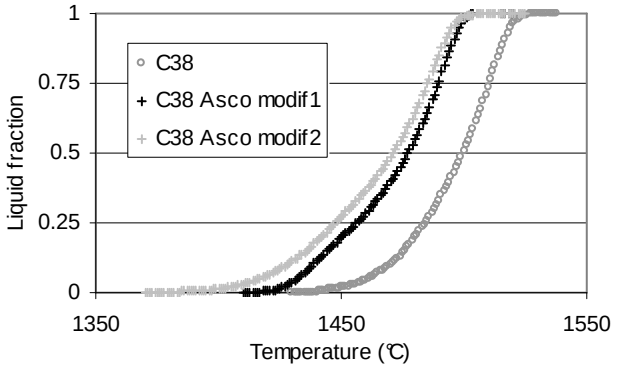

Fig. 8. Comparison of the liquid fraction between C38, C38 Asco modif 1 and C38 Asco modif 2.

With regard to Kazakov parameters, C38 Asco modif 2 exhibits better behaviour than C38 Asco modif 1 and C38 ones. The beginning of melting T_0 is lower, T_1 is lower, the solidification interval ($T_f - T_0$) is slightly larger (see table1) and the slope of the curve dF/dT is flatter at T_1 and T_f.

2.2 Alloys features during melting

Table1 gives main characteristic temperatures and slopes of the liquid fraction curve during melting at 20°/min. Alloys are classified following decreasing T_0.

Table1. Characteristic temperature and slopes

Alloys	T_0 (°C)	T_1 (°C)	T_f (°C)	Slope at T_1	Slope at T_f
C38	1430	1500	1536	0.0200	0.0019
C38 A. mod.1	1415	1478	1517	0.0185	0.0017
C38 A. mod.2	1379	1472	1520	0.0145	0.0007
C80	1361	1450	1491	0.0114	0.0003
100 Cr6	1315	1431	1487	0.0111	0.0004
100 Cr6 A.mod.1	1278	1402	1460	0.0097	0.0013

It is clear that for non alloyed steels the C38 Asco modif 2 gives the best results: T_0 and T_1 are lower, ($T_f - T_0$) is larger, the slopes at T_1 and T_f are lower than those of C38. It was used for the simulation of heating. Regarding low alloyed steels, 100 Cr6, 100 Cr6 Asco modif 1 show good behaviour.

3 CONCLUSIONS

The DSC measurements and corresponding liquid fraction versus temperature were used to study different alloys. For non alloyed steels, C38 Asco modif 2 shows better behaviour as regarding T_0, T_1, ($T_f - T_1$) and dF/dT (T_1, T_f) than C38. For low alloyed steels 100 Cr6 and 100 Cr6 Asco modif 1 show good behaviour. They could be chosen as candidates for thixoforming. We have pointed that the evolution of liquid fraction and the important parameters such as solidification interval solidus-liquidus are strongly dependent on the kinetic of melting (heating rate). This factor has an increasing importance on processing. This point will be intensively studied in our future research.

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