

Thixoforming M2 tool steel: a study of different feedstock routes

P. Kapranos, D. H. Kirkwood

Different aspects of thixoforming M2 tool steel feedstock produced through deformation recrystallization and partial melting (RAP) and through Sprayforming routes. The spheroidal microstructures obtained are compared as are the resulting properties after thixoforming. Experiences on die materials are described as are the various challenges of thixoforming high melting point alloys.

KEYWORDS:

thixoforming, steels, high melting point alloys, sprayforming, GFM, mechanical properties

INTRODUCTION

Since the discovery of Semi-Solid Metal Processing or Thixoforming in the 1970's at MIT [1], there have been significant developments in this technology. However, although thixoforming is now a commercial process, with components being produced each year for the automotive and for the consumer products/electronics markets mainly using aluminium and magnesium alloys, there is still an apparent lack of visible acceptance in manufacturing.

This apparent paradox can be explained if we separate the thixomolding variant from the thixoforming umbrella of processes. Thixomolding has achieved undisputed commercial success because it has concentrated on

specific markets using only magnesium alloys and utilizing a compact process that allows recycling. The rest of the thixoforming processes have had a long struggle in establishing credible material feedstock routes and recyclability of material feedstock.

Despite that, because of the fine microstructures and the high integrity associated with thixoformed products, thixoformed aluminium products have replaced steels and some forged, machined or cast aluminium parts, with the consequent savings in manufacturing time and weight. Thixoforming indeed produces complex near-net-shaped components of high integrity, with mechanical properties better than cast components but it needs to provide repeatability at the right cost in relation to competing processes.

Thixoforming has the potential to be a successful commercially viable manufacturing process but in order to achieve this it has to find its own niche in a number of market applications that will benefit from the advantages it has to offer.

In addition, thixoforming has to seriously establish itself as an effective 'hybrid' manufacturing alternative for shaping high melting point alloys.

Current research in the later field is concentrating on the deve-

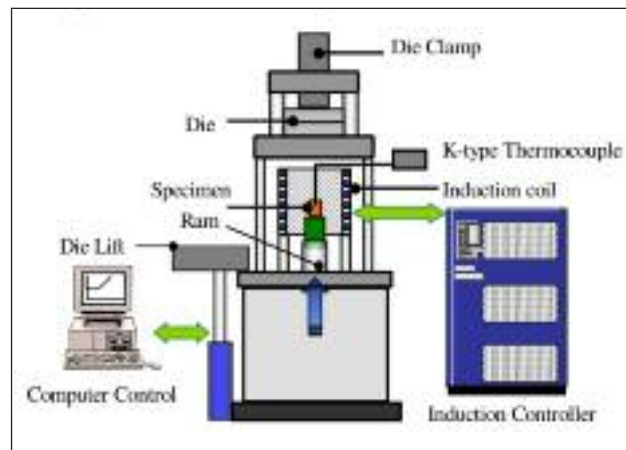


FIG.1 **Schematic of thixoforming Press at Sheffield.**

Schema di una pressa di tixofornatura a Sheffield.

lopment of high melting point alloys such as steels, iron-alloys, copper-alloys, superalloys and other exotic materials, to further exploit the potential benefits of this under-utilised metal forming technique.

However, although thixoforming of high melting point alloys offers exciting possibilities and tremendous potential, and has already been part of the original work of over thirty years ago, it is currently still in the research stage of development [2].

This paper will provide some insight of possibilities as well as the challenges involved when shaping such high melting point alloys by using M2 tool steel as a 'model' alloy.

EXPERIMENTAL SET-UP

The thixoforming of the chosen model alloy was carried out using a Servotest hydraulic press at Sheffield that had been designed specifically for research in semi-solid processing of alloys and this press has been fully described in the literature [3] and graphically shown in Figure 1. The procedure of thixoforming is schematically shown in Figure 2 and consisted of a number of steps: placing the billet in the induction coil within the vacuum chamber, evacuate and back fill with $N_2+5\% H_2$, heat the billet to the semi-solid state, use a 'softness indicator' to sense the condition of the billet and then inject into the die. Figure 3 shows a photographic series of images of the thixoforming process.

The 'softness indicator' consisted of electronic circuitry with a

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*Keynote lecture presented at the International Conference
"Hot Forming of Steels And Products Properties"
Grado, 13-16 Settembre 2009, organised by AIM*



FIG. 2
Steps used for the thixoforming operation at the Sheffield set-up.
Passaggi produttivi utilizzati per le operazioni di tixofornatura presso l'impianto di Sheffield.

laser beam being introduced below the billet which was standing on ceramic pins.

Once the billet achieved semi-solid status it would slump onto the pins, disrupt the sensing of the laser beam and thus trigger the thixoforming operation. Once experience was gained this system was superseded by a pre-set heating program. In addition, in order to achieve reasonably uniform heating throughout the volume of the billet, ceramic wool pads were placed on the top and bottom surfaces of the billets to reduce heat losses. The modeling of this process has also been described in the literature [4, 5].

As for the feedstock material, two production routes were investigated at the time; deformation by GFM and Sprayforming by



FIG. 3
Thixoforming sequence for M2 tool steel.

Sequenza per la tixofornatura dell'acciaio da utensile M2.

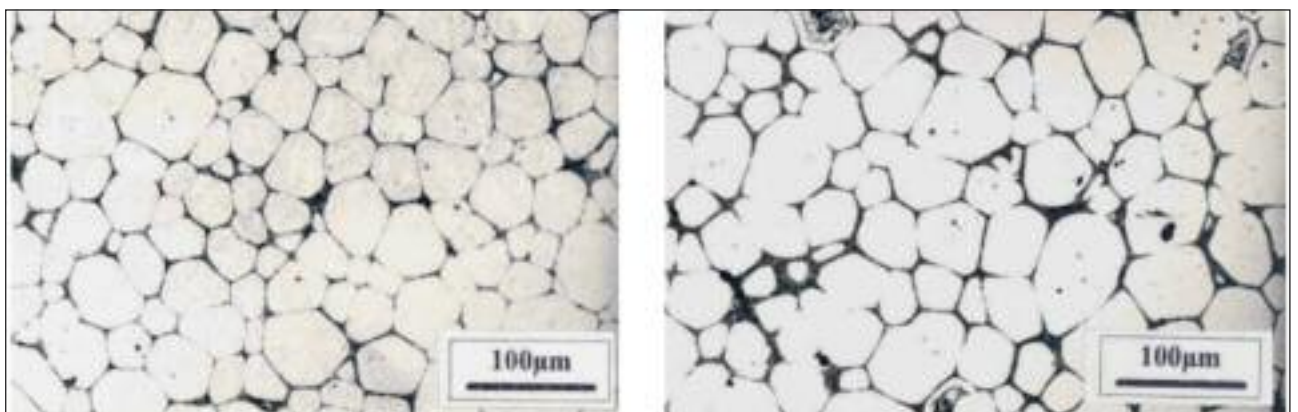


FIG. 4 **Sprayformed and GFM material feedstock microstructures exhibiting the familiar spheroidal microstructures obtained through isothermal heat treatment to the semi-solid state.**

Microstrutture dei materiali di base formati a spruzzo e con GFM che mostrano le tipiche microstrutture sferoidali ottenute tramite trattamenti termici isotermitici allo stato semisolido.

Ospray Metals Ltd. Figure 4 shows examples of the microstructures for these two routes.

RESULTS & DISCUSSIONS

Forgings of M2 tool steel of both feedstock production routes were thixoformed and their mechanical properties tested and compared with the as received materials. Figures 5, 6 and 7 show such results. Similar work has been also carried out using Stellite 21 alloys. Thxoforming of other grades of tool steels such as T15 and H13 has also been carried out by the Sheffield group as well as that of cast iron, ductile iron, stainless steel and other superalloys [2].

The main challenges in thixoforming these high temperature alloys have been: Billet uniformity, oxidation, injection delivery materials and die materials.

All these had great influence on the final properties of the thixoformed products. As has been described above, the billet uniformity was established by the use of ceramic insulation at the top and bottom surfaces of the billets.

This was not a fully satisfactory approach as on occasion it resulted in the inclusion of ceramic insulation into the final product adversely thus affecting properties (See Figure 10). Current technologies have overcome this challenge as can be seen in recent research by the research group based in Liege [6].

Oxidation was reduced by using a vacuum and gas protective atmosphere and once again any discrepancies there resulted in oxide inclusions in the final product. The injection materials challenge was solved by the use of ceramic pedestals (Syndanyo - cement based composite).

Finally the most problematic of the above challenges was the use of die materials. A number of die materials were used. Graphite of different grades and strengths was a convenient and 'cheap' material to use but it had the adverse effect of high conductivity resulting in chilling of the semi-solid slurry being injected and therefore leading to a number of solidification related problems discussed below. The use of ceramic and even 'sand' dies alleviated the problems of using graphite but introduced their own deficiencies; fracture, erosion, and cost.

As mentioned above the use of graphite dies created the problem of premature chilling of the injected slurry. This in effect created a solid 'box' with slurry still flowing through it as can be seen in Figure 9. Of course when the slurry filled the remaining part of the cavity by backing up on itself it created a lap which on testing was the source of cracking and therefore reduction in mechanical performance. The use of ceramic dies eliminated this problem and the mechanical properties obtained using ceramic dies were consistently less scattered than the ones obtained using the graphite dies.

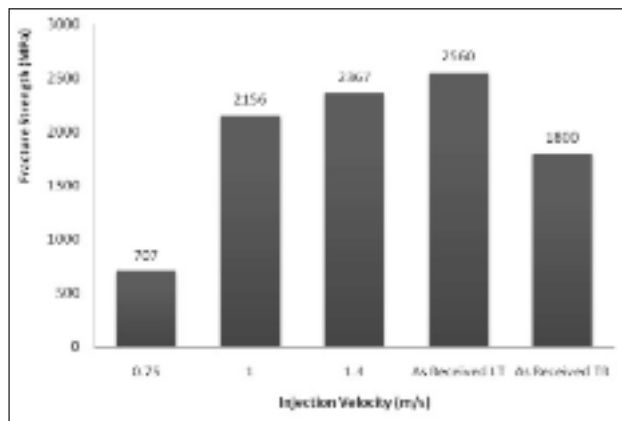


FIG. 5 Fracture strength of M2 as a function of injection velocity (GFM route feedstock). Values of as received material in the longitudinal and transverse directions are also shown.

Resistenza alla frattura dell'acciaio M2 in funzione di velocità di iniezione (GFM route feedstock). Sono mostrati anche i valori del materiale come ricevuto nelle direzioni longitudinale e trasversale.

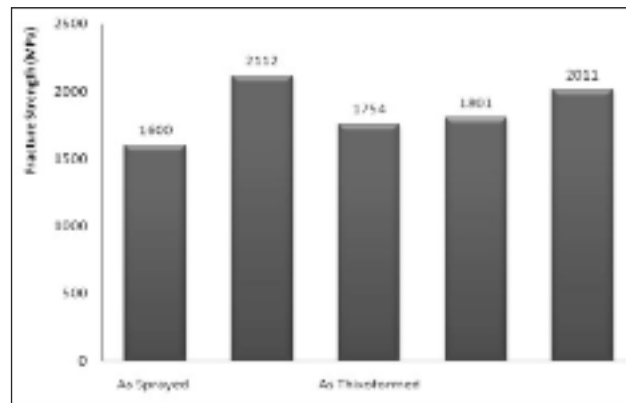


FIG. 6 Strength values of Sprayformed M2 tool steel: as sprayed and as thixoformed.

Valori di resistenza dell'acciaio da utensile M2 allo stato di prodotto per formatura a spruzzo e di prodotto tixofornato.

FIG. 7 Strength values of GFM M2 tool steel: as received (Longitudinal and transverse directions) and as thixoformed.

Valori di resistenza di acciaio da utensile M2 GFM allo stato di fornitura (direzione longitudinale e trasversale) e tixofornati.

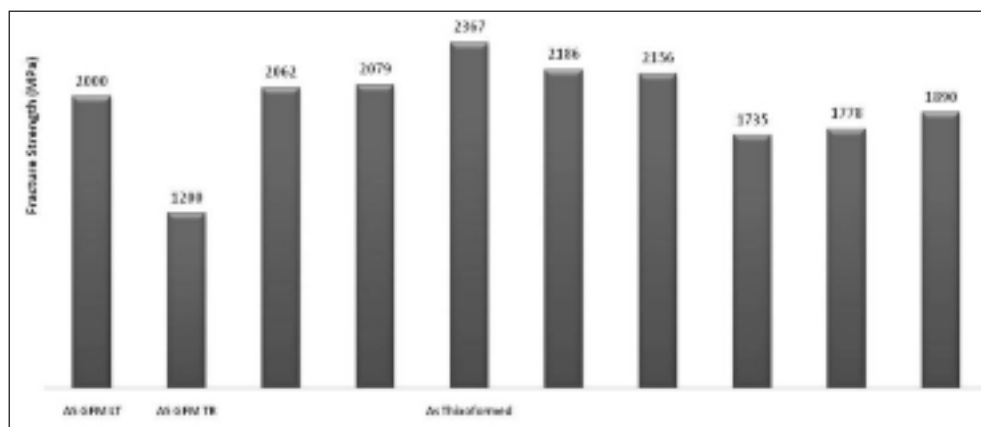




FIG. 8
Thixoformed M2 tool steel cog wheels and resulting typical microstructures: GFM feedstock (top) and Sprayformed feedstock (bottom). Other alloys are also shown in the picture.

Ruote dentate in acciaio da utensile M2 tixiformate e microstrutture tipiche risultanti: materiale di base GFM (in alto) e materiale di base prodotto mediante formatura a spruzzo (in basso). Nella figura vengono mostrate anche altre leghe.

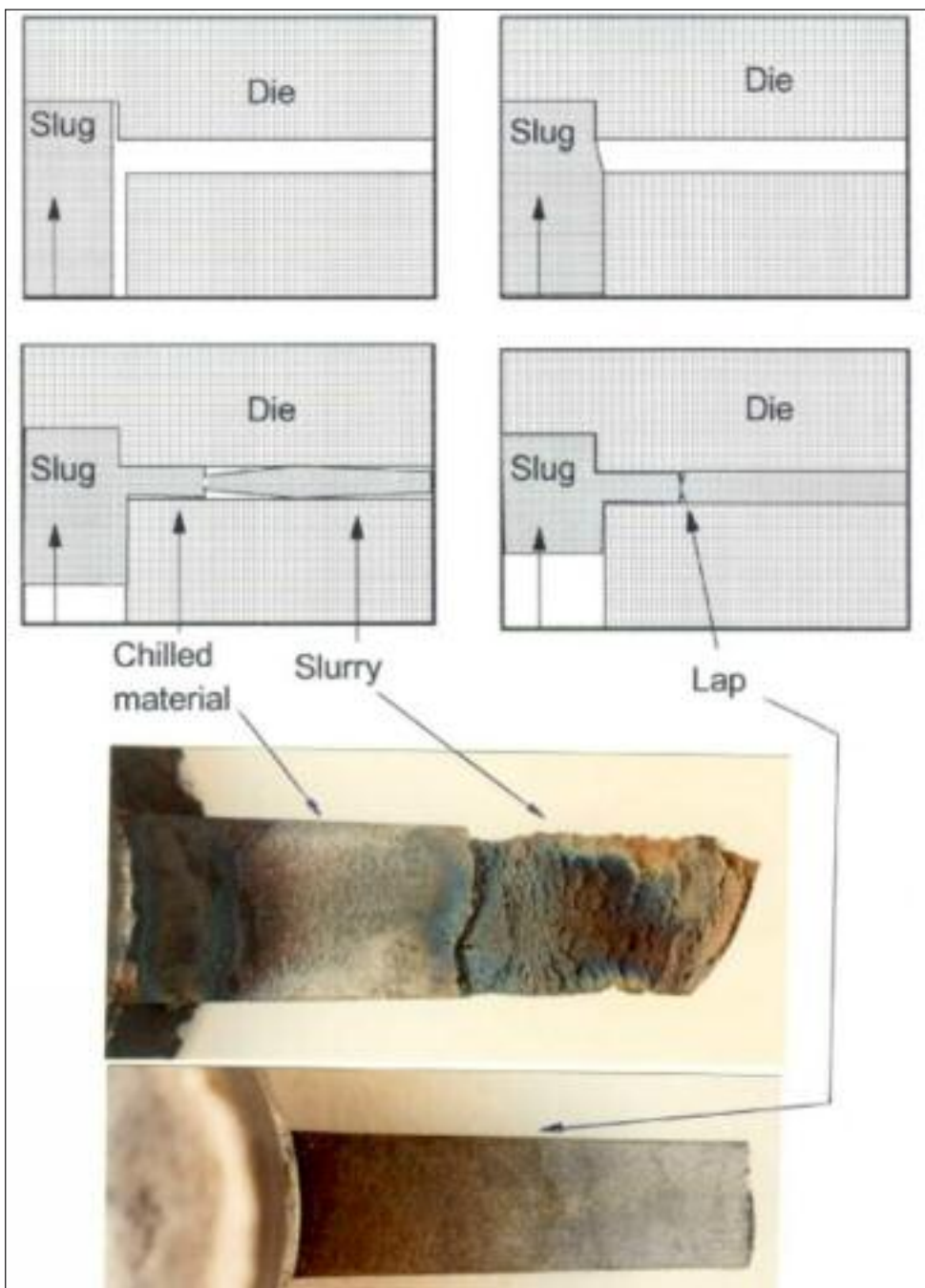
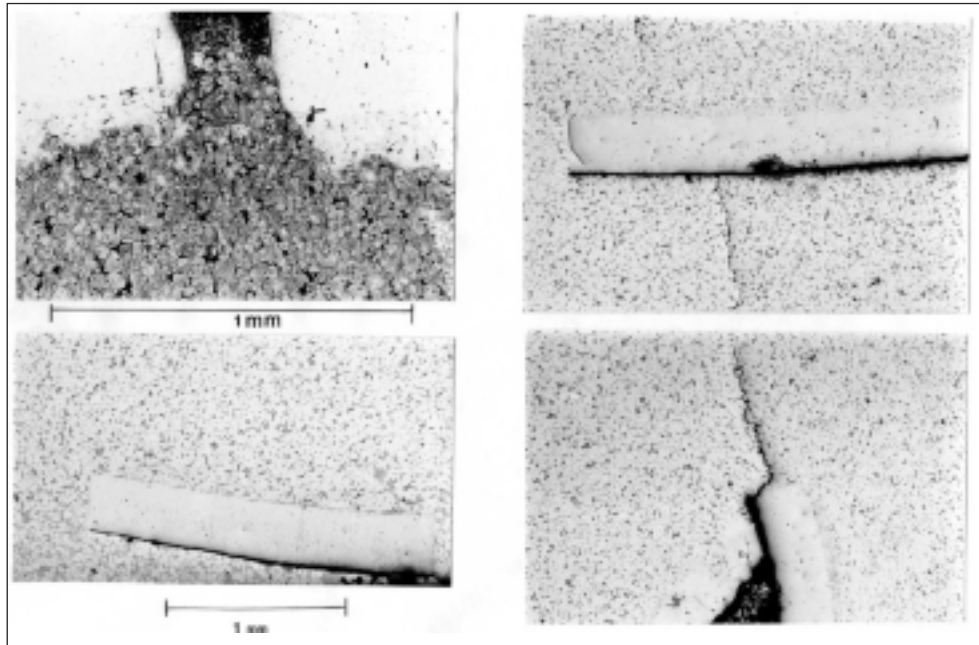


FIG. 9
Generation of laps in thixoformed 'fingers'.

Generazione di difetti in 'dita' tixiformate.

FIG. 10
Defects in thixoformed parts originating from embedded ceramic blanket material.

Difetti in pezzi tixofornati generati da materiale ceramico incorporato.



During these studies the results were statistically analyzed and the corresponding microstructures and possible defects were looked at in relation to the corresponding mechanical properties in order to draw reasonable conclusions. It was clear from the above that when the billets were thixoformed under reducing atmosphere, therefore containing no inclusions, within ceramic dies they consistently had good mechanical properties, on occasion better than those of the starting feedstock. Any discrepancies introduced through uneven heating, ineffective protective atmosphere and rapid chilling due to the die material all resulted in reduced mechanical properties.

Thixoforming of high temperature alloys is challenging but feasible. If sufficient care is taken in devising appropriate procedures and using appropriate materials for handling and delivering the semi-solid slurries intricate products can be obtained that exhibit good mechanical properties.

Since the work described in this paper was completed, a number of researchers have moved the dream of forming high melting point alloys in the semi-solid state closer to a commercial reality [7] but although promising, these efforts are far from complete. A European consortium under the support of the COST Office is currently working towards the possibility of bringing the efforts of past and present researchers in this field to fruition [8].

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Abstract

Tixofornatura di acciai da utensile M2: studio dei risultati ottenuti con materiali provenienti da diversi processi

Parole chiave:

acciaio, tixofornatura, processi

Nel presente lavoro sono stati analizzati diversi aspetti della tixofornatura di acciai da utensile M2 ottenuti attraverso diversi processi: deformazione, ricristallizzazione e fusione parziale (RAP) e Sprayforming.

Le microstrutture sferoidali ottenute sono state confrontate insieme alle proprietà rilevate dopo tixofornatura. Si descrivono esperienze su materiali da stampo e anche le varie sfide poste dalla tixofornatura di leghe ad elevato punto di fusione.