Structural changes in weld bead in TIG welded Zn–22Al–2Cu alloy plates after tension

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By utilising the tungsten inert gas welding process, plates of Zn–22Al–2Cu (wt-%) alloy were welded. The weld bead was tested under tension in the transverse direction in order to study the structural changes. Once the tension samples were fractured, the weld bead and the contiguous region were analysed by means of X-ray diffraction. It was found that the applied load through the parent metal is responsible for the transformations in the crystalline phases inside the weld bead. From spectrum analysis, the α'_M aluminium rich solid solution, the η'_M zinc rich solid solution and the ε'_M ($CuZn_4$) phases resulting from tension shifted to the low 2θ position. To explain these transformations, the reactions $\eta'_T \rightarrow \alpha'_M + \eta'_M + \tau'$ and $\tau' + \eta'_T \rightarrow \alpha'_M + \varepsilon'_M$ were considered. To supply the necessary thermal energy so that these reactions happen, the hypothesis that the friction in the slip planes at the moment of deformation it produced the required heat for atomic diffusion is established. Finally, with the aid of scanning electron microscope, the morphology of the contiguous region to the fracture was observed. Near the fracture line, the lamellas inside the two-phase dendrites showed a tendency to be guided in parallel address to that of the tension load. In addition, as a result of the heating process, a coarsening of these lamellas can be observed. In a practical sense, the observed results are points to favour in the selection of this alloy for structures since no thermal treatments are needed for its stabilisation after welding.

Keywords: Zn–22Al–2Cu alloy plates, TIG welding process, Fracture, Phase transformation, Two-phase dendrites

Introduction

The Zn–Al based alloys have reached a significant number of applications. The lightness of these alloys and their mechanical high resistance are some of their qualities that have promoted their use. Depending on the alloying elements and the obtaining process, the alloys based on Zn–Al modify their response to mechanical stimuli. In consequence, each new alloy based on Zn–Al is subject to a series of studies for characterisation and to develop new applications.

The present work is a study carried out for the alloy Zn–22Al–2Cu (wt-%). As observed, the addition of the third element (Cu) and its content (1·5–2·5) modifies the atomic structure, principally the lattice parameters. The solids of this alloy are constituted by two solid solutions; the η zinc rich solid solution and the α aluminium rich solid solution.[1] Other phases like τ' phase (Al_4Cu_3Zn) and ε phase ($CuZn_4$) are found to appear as a result of thermal treatments.[2] Moreover, depending on the obtaining process, different grain shapes will be present. Therefore, a pearlitic structure will be that corresponding to metallic pieces solidified at a low cooling rate,[3] while fine equiaxed grains and two-phase dendrites will be present in those solids prepared from the melt at high cooling rates.[4] On this alloy, the best mechanical properties have been attained with processes allowing high cooling rates (10^3–10^6 K s^{-1});[4] however, rapid solidification produces metastable phases that are retained to room temperature. The metallic materials of this alloy in metastable conditions are susceptible to thermal treatments; this situation can be considered an advantage since the mechanical properties can be controlled.

When conventional welding processes to join plates of this alloy are utilised, local zones are melted and then cooled. In all these cases, the fusion–solidification phenomenon carried out is a particular case of rapid solidification. In consequence, without considering the structure of the parent metal, the fusion zone will be invariably conformed by two-phase dendrites containing metastable phases.[5] In addition to the crystalline and granular structures, defects will be present inside the fusion zone, which will cause that this zone has a mechanical behaviour very different from that of the rest of the solid. In order to determine the heat treatments necessary to have an appropriate mechanical behaviour of the welding, studies on phase transformation, grain

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morphology and defects have been carried out in a systematic way.

As mentioned in the last paragraph, metastable phases will be present inside the fusion zone. It is possible to modify this thermodynamic metastable state by supplying enough energy; this energy can be of thermal or mechanical origin. The aim of this work is to demonstrate that the metastable state of the fusion zone can change to a different state by means of strain under stress. In other words, the phase transformation can be induced by mechanical means also. This finding constitutes an alternative that eliminates the need to apply heat treatments to tungsten inert gas (TIG) welded Zn–22Al–2Cu alloy plates, since the weld bead will be stabilised thermodynamically when it is subjected to load. The increase in the use of Zn–Al based alloys in the real world is well known; then, the practical use of this result in the construction of structures will help in the reduction of costs in comparison with some steels. Therefore, the result of this investigation, together with others already known, reinforces the growing tendency to utilise this metallic material.

Materials

Rolled plates, 6·5 mm thick, of the Zn–22Al–2Cu (wt-%) alloy were welded by utilising the TIG welding technique. Samples for test of tension, according to the standard A 370 of ASTM, were extracted from the welded plates. The samples were extracted in a manner that a small section of the weld bead was located in the centre of the neck zone and in transverse position to the tension force direction. It is worthy to point out that the welded plate cuts for the tension samples were made far from the weld start and end.

Afterwards, the zone of the sample containing the fracture was separated and mounted in resin. The resin was moulded in cylindrical form in accord to the dimensions of the microscope holder. Then, the separated zone was mechanically polished and then irradiated with X-ray. For metallography, the metallic part was grounded by using an aluminium foil jacket and silver paint.[1]

Experimental

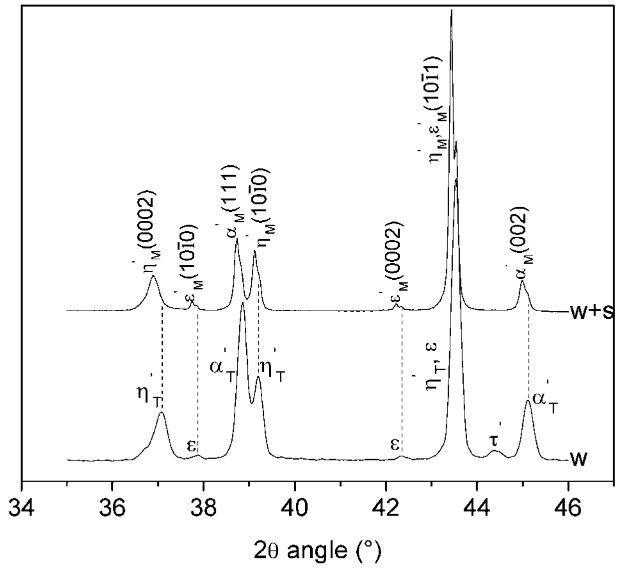
The samples were tested under tension by utilising a load cell of 10 kN. The utilised machine for the tension test was a Shimadzu Model 1875. Ultimate tensile strength values remain in between 126 and 148 MPa. The discrepancy in the calculated values was due, principally, to the differences in weld penetration. In addition, in most of the tested samples, the fracture was located inside the weld bead.

For crystal analysis, a model D-5000 Siemens machine was utilised, and nickel filtered X-rays with a wavelength of 1·5406 Å were used. Finally, micrographies of the microstructure were obtained with the aid of a JEOL JSM-6060 LV scanning electron microscope. A metallographic reactive solution of CrO_3, Na_2SO_4 and H_2O was used to develop the microstructure.[6,7]

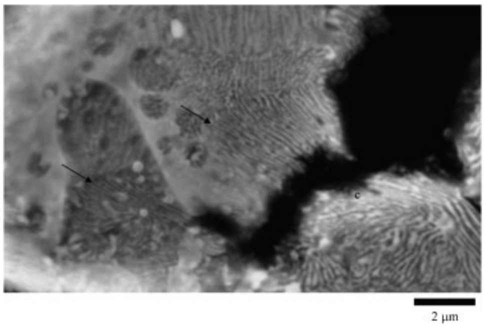
Results and discussion

X-ray diffraction

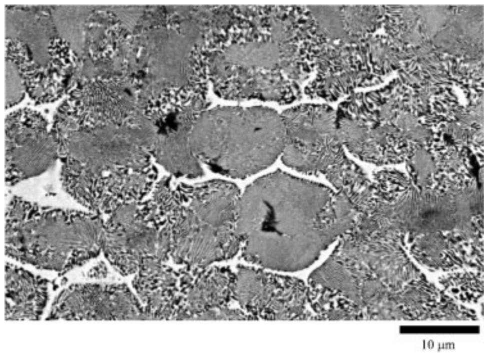
As mentioned in the section on ‘Introduction’, the objective of this work is to show that the phase transformations can also take place through a mechanical mean as the tension load. Figure 1 shows two superimposed X-ray diffraction spectra: the spectrum of below corresponds to welded samples, while the spectrum of upside corresponds to welded and strained samples. To distinguish if the obtained phases come from a thermal treatment (T) or a mechanic process (M), subindexes were used. By comparing the positions of peaks (2θ) of the upper spectrum with the peaks of the inferior spectrum, several details can be observed. First, with the exception of the peak produced by the plane (0002) of the η'_M hexagonal phase, all the peaks in the upper spectrum show overlapping peaks. By analysing the possibilities, two peaks are overlapped at each 2θ position on the upper spectrum. By observing the dash line in Fig. 1, it is clear that (1) the peak at the right in each pair of overlapped peaks on the upper spectrum is the same as that in the spectrum of below, and (2) the left peak in each pair of overlapped peaks on the upper spectrum originated from the diffraction of atomic planes of the transformed phases. The displacement to the left of the peaks in the upper spectrum indicates a d spacing increase (according to the Bragg law), which indicates that there was a variation in the solute content of the original phases.[8] Since the upper X-ray diffraction pattern was obtained from welded and strained samples, it is clear that the shift to the left of the peak positions was caused by the tension force applied; that means that the transformations observed are the result of the energy supplied by mechanical means. Table 1 shows the d spacing corresponding to each band and the d spacing increase (Δd) value. Second, the upper spectrum shows also that the original phases and the transformed phases are coexisting; this fact indicates that the number of obstacles for dislocations motion is bigger than that in the samples only welded. Therefore, the welded and strained samples will show the highest hardness numbers in the weld zone. Third, by comparing the intensities in each pair of



1 Spectra obtained from TIG welded Zn–22Al–2Cu (wt-%) alloy plates: (W) spectrum from weld bead of TIG welded plates; and (W+S) X-ray diffraction pattern obtained near fracture of TIG welded plates, which were tested under tension load



2 Micrograph that shows some aspects of fracture under tension load of TIG welded Zn–22Al–2Cu plates: in image, lamellas stayed oriented in parallel address to tension load direction (marked →). In detail, coarsening of lamellas that are close to fracture can be distinguished (marked c)



3 Structure of areas far from fracture originated by load of tension: observing the contour of the grains is clear the microstructure of these areas remains undeformed; in detail, inside the grains can be seen different degrees of transformation

overlapped peaks, it is also clear that the intensity of the transformed phase is bigger; consequently, the proportion of crystalline phases in the transformed state is dominant. Finally, by observing the spectra in Fig. 1, it can be seen that the τ' phase (Al_4Cu_3Zn) disappears with strain. Furthermore, by considering the components of this phase, their total dilution would be the result of 'mechanically assisted atomic diffusion'. This fact means that the atomic diffusion is enhanced by local heating;[3] this heating is the result of the atomic friction produced at the moment that strain is occurring. This local heating is difficult to be estimated, since the shoulders of the tension test machine have a great mass, which makes that it cannot detect any increase in temperature. Once the local temperature reaches the necessary value so that the cellular reaction $\eta'_T \rightarrow \alpha'_M + \eta'_M + \tau'$ occurs, the obtained products are easily observed.[9] Finally, by following a similar reasoning, the τ' phase disappears as a result of the four phase transformations $\tau' + \eta'_T \rightarrow \alpha'_M + \varepsilon'_M$.[10]

Scanning electron microscopy

As mentioned in the section on 'Experimental', the samples under tension failed inside the weld bead in all cases. The lack of a complete penetration of the welding left holes at half of the plate thickness. This fact is the cause of stress concentration in the extremes of the hole that promoted the propagation of the same defect until fracture occurs. Under these conditions, it is worth of mention that the welding bead will suffer and show a light plastic deformation, since the welding bead is predominantly of fragile character. Figure 2 shows the microstructure of the grains next to the fracture line. As can be observed, the lamellas at the interior of the two-phase dendrites show a tendency to be oriented in the direction of the applied load (i.e. in normal direction to the fracture line). Furthermore, it is clear that these lamellas have been coarsened. Finally, in order to compare the granular structure far from the weld bead, Fig. 3 shows a micrograph with the typical structure of the parent metal.

Conclusions

Transformations of phases occur in the weld bead when a mechanical tension is applied. The α'_M aluminium rich solid solution, η'_M zinc rich solid solution and ε'_M ($CuZn_4$) phases appear in the fusion zone after the plastic deformation because of the stresses concentration in this zone. The cell parameters of these phases are longer than those of the thermal phases (α'_T, η'_T, ε) The α'_M, η'_M and ε'_M phases are coexisting with the α'_T, η'_T and ε phases, which promotes the increase in discontinuities and consequently hardening. The τ' phase (Al_4Cu_3Zn) disappears with deformation and its components are contributing in the formation of the new phases α'_M and ε'_M. To explain the observed transformations the

Table 1 Values of interplanar *d* spacing according to Bragg law in different crystalline phases of tested sample under tension load: X-ray diffraction measures were obtained close to fracture

Atomic plane	Crystalline phase *d* spacing/Å	Crystalline phase *d* spacing/Å	Δd/Å
(0002)	η'_T 2·4237	η'_M 2·4348	0·0111
$(10\bar{1}0)$	ε 2·3757	ε'_M 2·3816	0·0059
(111)	α'_T 2·3172	α'_M 2·3228	0·0056
$(10\bar{1}0)$	η'_T 2·2951	η'_M 2·3006	0·0055
(0002)	ε 2·1334	ε'_M 2·1380	0·0046
$(10\bar{1}1)$	η'_T, ε 2·0770	η'_M, ε'_M 2·0814	0·0044
(002)	α'_T 2·0089	α'_M 2·0138	0·0049

reactions $\eta'_T \rightarrow \alpha'_M + \eta'_M + \tau'$ and $\tau' + \eta'_T \rightarrow \alpha'_M + \varepsilon'_M$ are considered.

Close to fracture line, the lamellas inside the two-phase dendrites showed tendency to be guided in the address of the applied load, which constitutes evidence that plastic deformation happened here. Coarsening of the lamellas inside the two-phase dendrites was observed. The coarsening of the lamellas was the result of a local increase of the temperature produced by the atomic friction during deformation process.

Finally, no heat treatments are needed in TIG welded Zn–22Al–2Cu alloy plates. The weld bead will reach the most stable thermodynamic state when the welded couples are subjected to load.

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