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Response of Some Cast Zinc-Base Alloys (37.5% Al) Comprised of Nickel/Silicon under Different Tensile Loading Conditions

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Observations were made during tensile testing of some zinc-base alloys (37.5% Al) comprised of nickel/silicon at different strain rates and temperatures. The zinc-base alloy without nickel/silicon was also tested under identical conditions to see the effects of the alloying elements on the tensile (strength and elongation) properties.

The nickel/silicon-free alloy attained tensile properties superior to those samples alloyed with the elements. Moreover, reducing content of copper deteriorated the properties of the alloy system. An increase in silicon content produced similar effects. In general, higher strain rates led to better tensile properties, within limits. Further, strength of the samples deteriorated with test temperature while elongation followed a reverse trend. However, the presence of nickel/silicon reduced the temperature sensitivity of the strength of the alloy system.

The behavior of the alloys is discussed in terms of specific features of their microconstituents.

Keywords mechanical properties, microstructure, tensile tests, Zn-Al alloys

1. Introduction

Two major limitations of zinc-base alloys comprised of 8 to 28% Al, 1 to 3% Cu, and ~0.05% Mg, limiting the range of their applications, include inferior elevated temperature properties and dimensional instability. The dimensional instability occurs because of their copper content above 1% (Ref 1, 2). One effective measure to reduce the problems includes partial replacement of copper by high melting elements in the alloy system (Ref 3, 4). Higher amounts of aluminum (than mentioned earlier) have also been noted to be beneficial to some extent (Ref 5).

Available information suggests that development and systematic characterization of mechanical and wear properties of different zinc-base alloys can help in understanding the behavior of the alloy system and increasing the range of effective application.

Thus, an attempt has been made to synthesize some Zn-base alloys (37.5% Al) comprised of varying quantities of elements like copper, silicon, and nickel and to evaluate their tensile properties at different strain rates and temperatures. The response of the alloys is discussed in terms of the behavior of their different microconstituents, which in turn is controlled through specific operating test conditions. The nickel/silicon-free alloy was also subjected to identical test conditions for comparison purposes.

Table 1 Chemical composition of the zinc-base alloys

		Composition, wt%					
No.	**Specimen**	**Zn**	**Cu**	**Al**	**Mg**	**Si**	**Ni**
1	Nickel/silicon-free alloy	bal	2.5	37.5	0.03	…	…
2	Nickel containing alloy	bal	2.0	37.5	0.03	…	0.3
3	Silicon containing alloy type 1	bal	2.5	37.5	0.03	4.0	…
4	Silicon containing alloy type 2	bal	1.0	37.5	0.03	2.0	…
5	Silicon containing alloy type 3	bal	1.0	37.5	0.03	4.0	…

2. Experimental

The zinc-base alloys (Table 1) were prepared by a liquid metallurgy route using permanent molds in the form of 20 mm diameter, 150 mm cylindrical rods. Microstructural characterization of the metallographically polished samples was performed using an optical microscope. The metallographic specimens were etched with diluted aqua regia prior to examination.

Tensile tests were carried out on samples having 4 mm gage diameter, 22 mm gage length at (a) different strain rates (3.8×10^{-1}/s, 1.52×10^{-2}/s, 1.52×10^{-3}/s, and 1.52×10^{-4}/s at ambient temperature (35 °C) and (b) different test temperatures (35, 60, 100, 150 and 200 °C) at 1.52×10^{-3} per second strain rate. The reported data points represent an average of three observations.

3. Results

Figure 1 represents the microstructural features of the zinc-base alloys. The nickel/silicon-free alloy reveals the presence of primary α dendrites surrounded by eutectoid $\alpha + \eta$ and ε phases (Fig. 1a, regions marked A, B, and arrow, respectively). Addition of nickel/silicon to the alloy system

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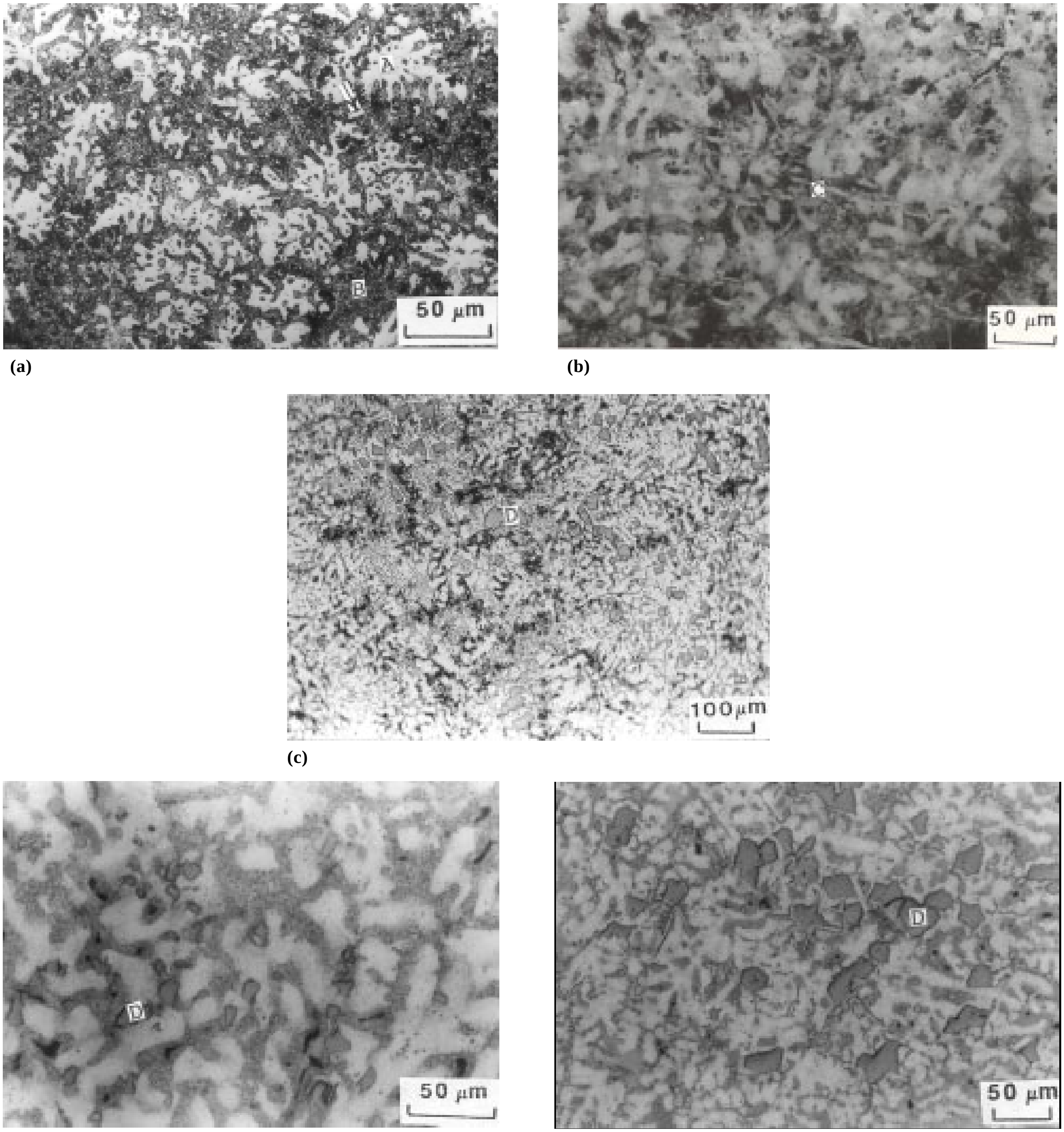
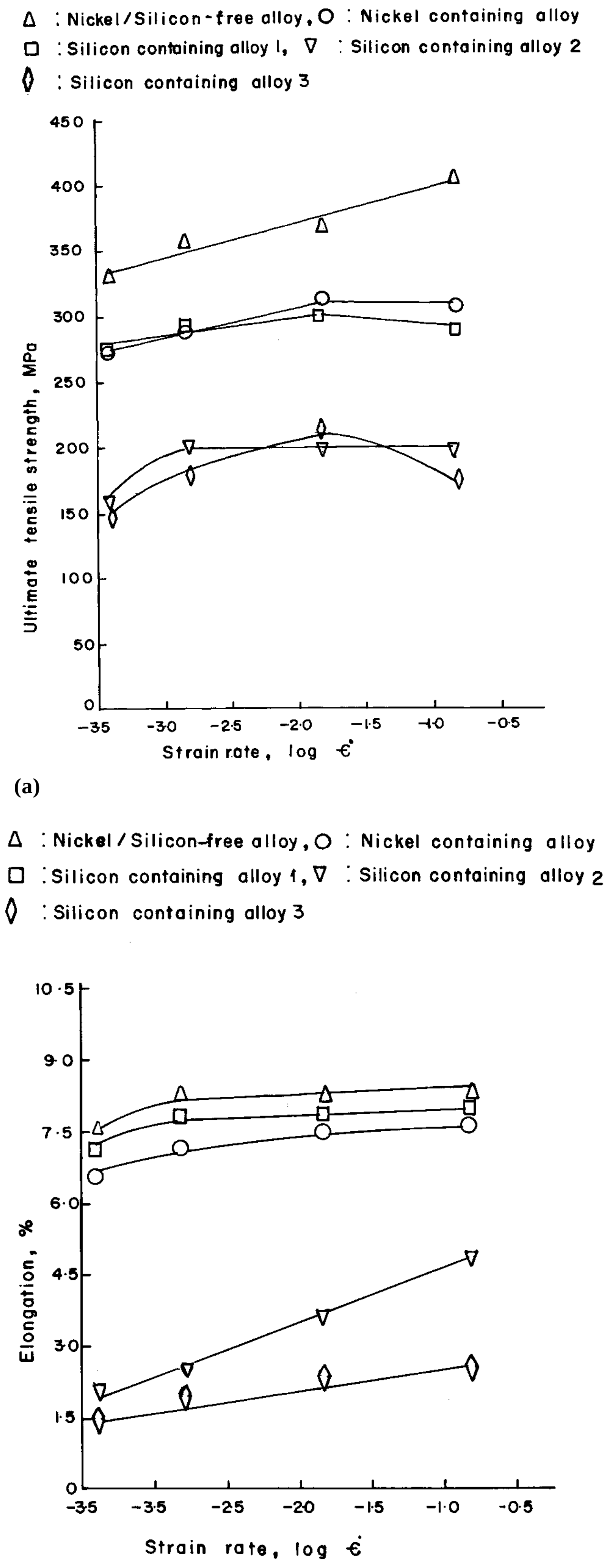
caused the formation of phases comprised by the elements (Fig. 1b to e, regions marked C and D, respectively).

Tensile strength and elongation of the alloys are plotted as a function of strain rate in Fig. 2(a) and (b), respectively. The nickel/silicon-free alloy attained maximum strength followed by that of nickel-containing samples and silicon-comprised alloys 1, 2, and 3 (Fig. 2a). The samples alloyed with nickel and silicon-containing alloy 1 attained comparable strength. Strain rate initially increased the strength of the alloys in general, whereafter a mixed trend was observed (Fig. 2a). The strength of the alloys improved with increased copper content while silicon affected this property in an opposite manner.



(a) (b) (c) (d) (e)

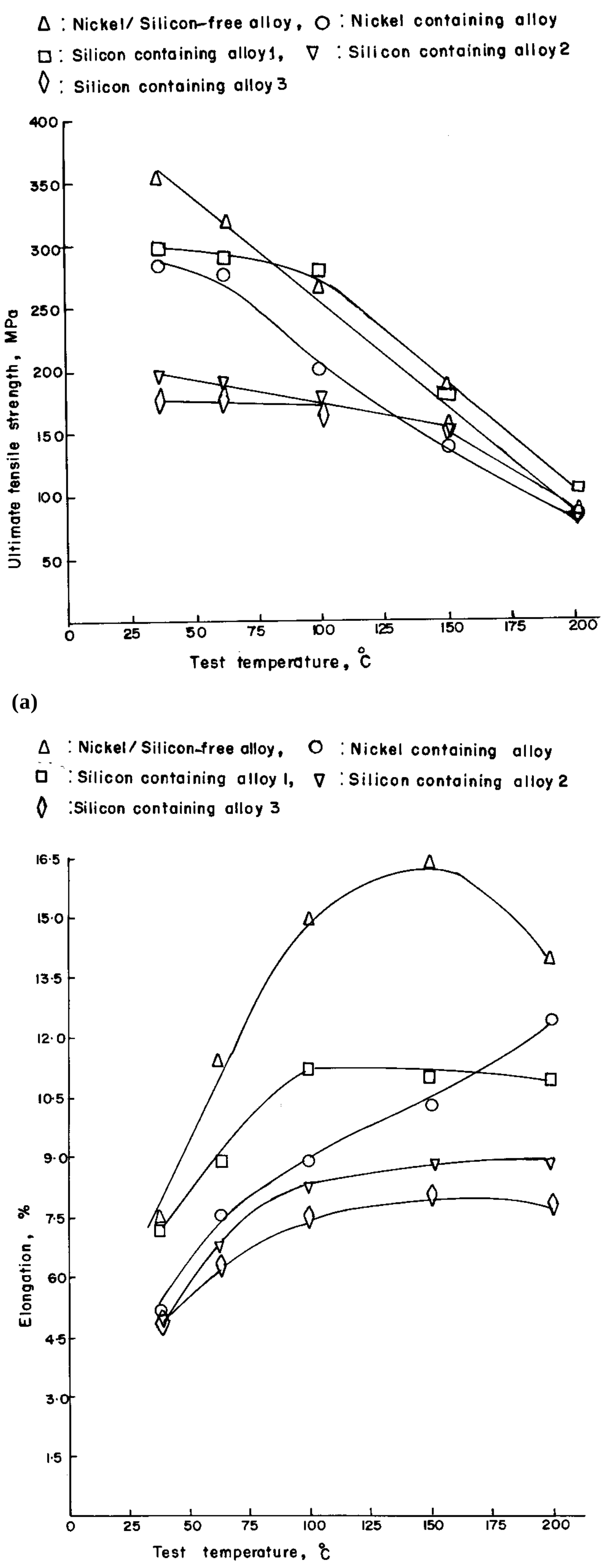
Fig. 1 Microstructure of zinc-base alloys containing (a) no silicon/nickel, (b) nickel, (c) silicon alloy 1, (d) silicon alloy 2, (e) silicon alloy 3. A, primary α. B, eutectoid $\alpha + \eta$. Arrow, ε. C, nickel containing phase. D, silicon particles



(a)

(b)

Fig. 2 Tensile properties of the zinc-base alloys as a function of strain rate at ambient temperature (35 °C) showing (a) strength and (b) elongation



(a)

(b)

Fig. 3 Tensile property versus test temperature plots for the zinc-base alloys showing (a) strength and (b) elongation at a strain rate of 1.52 × 10^{-3}/s

Elongation of the alloys improved with strain rate (Fig. 2b). In this case, the nickel/silicon-free alloy had the largest elongation, while the minimum elongation was observed for the silicon-containing alloy 3; the silicon containing alloys 1 and 2 and nickel-comprised samples attained intermediate elongation property (Fig. 2b). Moreover, elongation of the silicon-containing alloys was influenced by the presence of silicon and copper (Fig. 2b) in a manner similar to that influencing strength (Fig. 2a).

The influence of test temperature on the tensile properties of the alloys is shown in Fig. 3. Lower temperatures enabled the nickel/silicon-free alloy to exhibit maximum strength and elongation (Fig. 3a and b). The trend observed by the alloys at elevated test temperatures was nearly identical (Fig. 3) to that mentioned earlier (Fig. 2). However, the presence of nickel/silicon led to a reduced temperature sensitivity of the strength property of the alloy system at elevated temperatures (Fig. 3a). Further, elongation of the alloys initially improved with temperature while a further increase in test temperature produced a mixed effect (Fig. 3b). Also, the silicon-containing alloy 1 attained superior elevated temperature strength to that of the alloy with nickel (Fig. 3a).

4. Discussion

Properties of materials depend on a number of factors relating to material characterization and experimental variables. Material related parameters include the nature of different microconstituents in relation to such properties as thermal stability, microcracking tendency, and load bearing as well as the capability of a phase to accommodate another (less compatible) constituent and to undergo strain hardening (Ref 4-7). As far as conditions of tensile loading are concerned, strain rate and test temperature greatly control the response of materials (Ref 7-10). Further, strain hardening and thermal stability improve the tensile properties of materials while microcracking produces a reverse effect (Ref 4, 6-10). It has also been observed that strain hardening and microcracking characteristics become effective at low test temperatures while thermal stability controls the properties at elevated temperatures (Ref 4, 6, and 7). Thus, the overall influence of the material related parameters depends on test conditions to a considerable extent.

From microstructural considerations, the soft $\alpha + \eta$ phases (Fig. 1), which are solid solutions of zinc and aluminum in each other respectively, carry the load (Ref 11) during tensile loading. Copper goes into solid solution when present in zinc-aluminum alloys in quantities less than 1%, while at higher mass fraction, the element forms metastable ε phase (Ref 12); the element strengthens the (zinc-aluminum) alloy system. Silicon appears as discrete particles (Fig. 1c-e, regions marked D) while nickel forms nickel comprised compound (Fig. 1b, region marked C) respectively as discussed elsewhere (Ref 13). It is noted that the (silicon-particle and nickel-containing) phases introduce microcracking tendency at low temperatures (Ref 14) while suppressed cracking tendency under high temperature conditions allows them to impart thermal stability to the alloy system (Ref 4, 14).

Improvement in strength and elongation properties of the alloys with strain rate (Fig. 2) results from a lesser (negative) contribution of the weaker, crack-sensitive microconstituents in view of shorter test durations involved in larger strain rates (Ref 7). Under the circumstances, a major role in load transfer toward controlling the response of materials is played by the strong phases/regions causing strain hardening, since the weaker sections of the gage area do not have time to adversely affect the properties of the alloys (Ref 7). The latter aspect becomes more effective at lower strain rates in view of longer test durations and hence inferior tensile properties result (Fig. 2). However, this trend was maintained up to a specific strain rate, especially in the case of the silicon/nickel containing alloys. In fact, the tensile properties either remained nearly constant (due to a counter balancing effect of the strain hardening and microcracking characteristics) or tended to decrease (as a result of the predominating cracking tendency) at still higher strain rates (Fig. 2).

Deteriorating strength property of the alloys with test temperature could be attributed to increased deformability and plasticity, which also caused the elongation of the samples to become larger (Fig. 3). However, the presence of nickel/silicon-containing phases restricted the extent of deformation of the alloy system by imparting improved thermal stability (Ref 4, 13), silicon being more effective than nickel in view of the higher silicon melting point. As a result, the silicon/nickel containing alloys exhibited reduced temperature sensitivity for both strength and elongation (Fig. 3).

Inferior tensile properties of the alloys comprised of the elements (nickel/silicon) than nickel/silicon-free samples at low test temperatures (Fig. 2 and 3) could result from the predominating microcracking tendency of the former introduced by the hard (nickel/silicon containing) constituents (Fig. 1b-e). The absence of such crack sensitive phases in the nickel/silicon-free alloy led it to attain superior mechanical properties at low temperatures while its low melting, load bearing $\alpha + \eta$ became less effective at higher temperatures causing strength to deteriorate (Fig. 3).

Copper seems to control mechanical properties of the alloy system to a great extent, especially at low test temperatures (higher the copper content, better the properties); the influence gradually reduces with test temperature (Fig. 2 and 3). Further, the effects produced by silicon on the properties of the alloys were noted to be opposite to those produced by copper, but copper was much more effective than the former.

5. Conclusions

Observations made in this study indicate significant changes in tensile (strength and elongation) properties of the alloys as a result of compositional alterations. This suggests the possibilities of developing modified zinc-base alloys with various combinations of properties. Specific characteristics like microcracking tendency, thermal stability and load bearing, and strain hardening properties of microconstituents greatly control the response of the alloys. The contribution of the mentioned factors has also been observed to change with varying test conditions such as strain rate and temperature. From an alloy composition point of view, (partial) substitution of copper through high melting elements like nickel/silicon deteriorates the low temperature mechanical properties of the alloy system while proving beneficial in reducing temperature sensitivity. Further, copper becomes more effective than nickel/silicon; the influence of copper decreases at higher temperatures while the reverse holds for nickel/silicon.

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