

Production of Thin-Walled Steel Structures Through Gas Carburization of Fully Reduced Metal-Oxide Mixtures

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Abstract

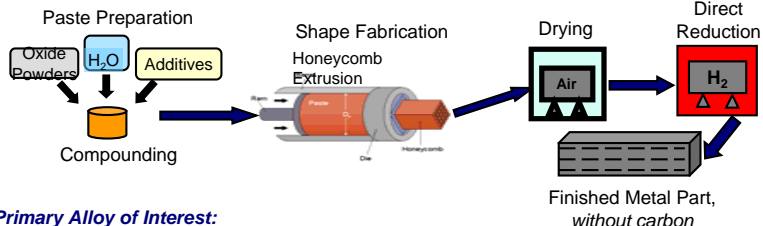
The gas carburization of fully reduced metal-oxide powder mixtures as a novel technique to produce thin-walled steel structures is evaluated. Specifically, the carburization of extruded tape with wall thickness of ~200µm and hollow spheres with wall thickness of ~50µm are investigated. Samples are carburized in atmospheres with differing CO/CO₂ ratios such that the kinetics of the process can be investigated. Additionally, processing parameters are selected such that the carbon content reaches that of the desired steel alloy without the occurrence of metal dusting.

Objectives

- Extrude thin tape of 4140 composition with all alloying elements present except for carbon
- Determine gas carburization parameters (time, temperature, atmosphere composition) necessary to successfully introduce carbon into the part without the occurrence of metal dusting
- Demonstrate that carbon contents above the eutectoid composition (~0.80 wt% C) can be achieved quickly using gas carburization
- Use gas carburization to reach 0.40 wt% C in thin tape samples of 4140 composition

Technical Approach

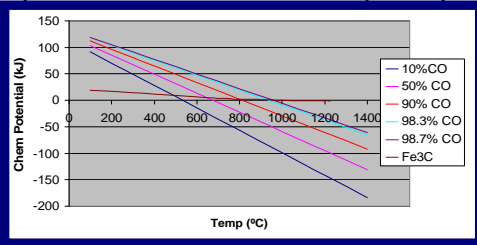
Step 1: Shape Fabrication from Metal-Oxide Powder Mixtures



Primary Alloy of Interest:

4140	C (wt%)	Mn (wt%)	Cr (wt%)	Mo (wt%)
	0.37-0.43	0.75-1.00	0.80-1.10	0.15-0.35

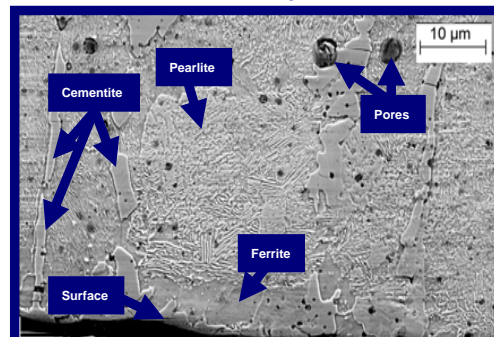
Step 2: Gas Carburization in a CO/CO₂ Atmosphere



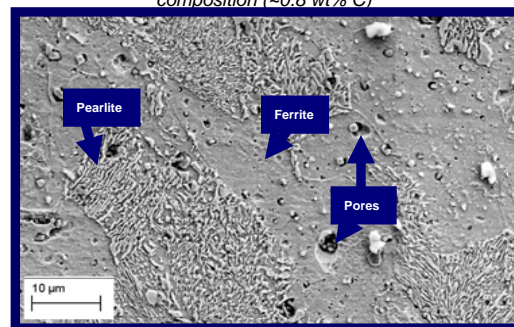
A plot of the chemical potential of carbon in a CO/CO₂ atmosphere and for the formation of Fe₃C vs. temperature allows for the determination of the process parameters such that metal dusting will not occur. If the chemical potential of the atmosphere is greater than that of Fe₃C, metal dusting can occur. The equilibrium surface concentration (C_s) of carbon on the part is determined by the composition of the atmosphere.

Results

Extruded Tape

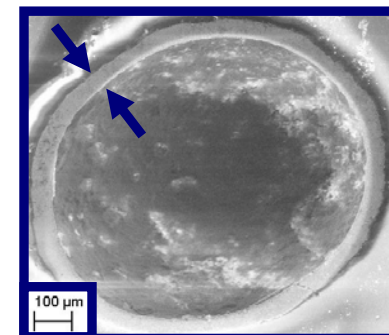


The edge of the cross-section of extruded 4140 tape (post-carburization at C_s = 1.0 wt% C for 30 minutes) shows areas of proeutectoid cementite, areas of pearlite and a decarburized layer of ferrite along the sample surface. This microstructure is characteristic of steels with carbon contents above the eutectoid composition (~0.8 wt% C)

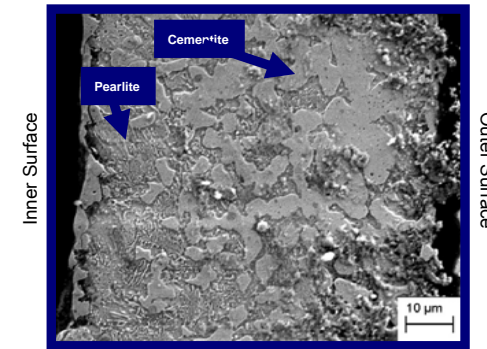


An image taken at the center of the cross-section of extruded 4140 tape (post-carburization at C_s = 0.40 wt% C for 30 minutes) shows only areas of pearlite and ferrite. Preliminary measurements show the carbon content is ~0.32 wt% C.

Hollow Spheres



An SEM image of the cross section of a hollow sphere (post carburization at C_s = 1.0 wt% C for 30 minutes), showing a wall thickness of ~50µm and sphere diameter of ~0.9mm.



An image of the sphere cross-section at a higher magnification shows areas of pearlite and cementite. A greater volume fraction of cementite is observed toward the outer surface, suggesting a carbon gradient through the sample, though compositions above the eutectoid have been reached.

Conclusions

- Gas carburization parameters have been determined such that metal dusting does not occur for samples with low-alloy steel compositions.
- Experiments have shown that compositions above the eutectoid are easily reached in less than 30 minutes
- Carbon compositions of 0.40 wt% C are nearly reached in 30 minutes for thin tape geometries

Future Work

- Carry out further experiments to determine more precise carburization times.
- Quench samples to form martensitic microstructures
- Use nanoindentation to determine hardness gradients through the cross-section as well as for mechanical property comparison of conventionally made parts
- Use mass spectrometry to determine reaction kinetics