Life Cycle Modeling of Propulsion Materials

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Project ID: PM034

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Overview

Timeline

- Start – Oct. 2008
- Finish – Sept. 2010 & beyond
- 10% Complete for FY10

Budget

- Total project funding
  - $80K/year (FY'09)
  - $185K (FY'10)

Barriers

- Advanced propulsion materials needed to meet various multi-year Vehicle Technology program goals are several times more expensive than conventional steel – would they be economically viable, energy-efficient, and environmentally friendly when commercialized?
- Specific technology improvements affecting major cost drivers detrimental to technology viability
- Material viability in most cases determined on the basis of part by part substitution
- Vehicle manufacturing instead of life cycle consideration

Study Objective

Estimate the Cost-effectiveness of the CF8C+ Cast Austenitic Stainless Steel in Automotive Applications

Milestones

- **Complete the cost-effectiveness analysis of CF8C+ cast austenitic stainless steel in automotive applications (Completed Oct.'09) – Presentation Focus**
- **Complete the life cycle analysis of alternative engine designs (July'10)**
- **Complete the life cycle energy analysis of CF8C+ cast austenitic stainless steel in automotive applications (Sept.'10)**

Approach

- **Cost-effectiveness estimation based on a range of competing, corrosion-resistant stainless steel and nickel-base superalloys currently used in applications where CF8C+ might be used**
  - Cast (SiMo, Ductile Ni-Resist, HK30, HF, 625, and CN-12)
  - Wrought (617, Super 304H)

- **Analysis level considered both material (per lb replacement basis) and specific component application (addressing manufacturing differences)**
  - Material (mass and cost savings and their ratio – both material and operation life time fuel cost savings considered)
  - Component (exhaust manifold and gas turbine inner case)

Component Cost Modeling Approach – Process Cost

- Process cost models explicitly represent the major processing steps in the manufacture of products
- Specific manufacturing technologies are modeled at each step, including assumptions about key technical and economic parameters
- Values of all inputs associated with each process step are estimated by process step and for the production process as a whole
- Output from the first process step—total cost at the step and costs of individual inputs—becomes an input to the second process step and so forth
- Spreadsheet software

CF8C+ Cast Stainless Steel

- A heat resistant, cast, corrosion resistant austenitic stainless steel
  - Major alloying elements: 18-22 wt% Cr; 11-14 wt% Ni; 0.3-1.5 wt% Nb; 0.05-0.15 wt% C
  - 0.03 wt% sulfur provides a four-fold creep life improvement at 850^{o}C
  - 2-10 wt% Mn improves work-hardening, metal's fluidity, and also is an effective austenite stabilizer at a lower cost than Ni
  - Appropriate Nb:C ratio provides high-temperature strength without reducing ductility (better than Nb-containing stainless steels)
- Suitable for applications where it is exposed to high temperatures and extreme thermal cycling such as air/exhaust-handling equipment for diesel and gasoline engines and gas-turbine engine components
  - Tensile and creep strength in excess of 600^{o}C, cyclic oxidation resistance >700^{o}C, room temperature ductility, long-term resistance to cracking during severe thermal cycling
  - Good castability and weldability, and no heat treatment requirement
  - Strength comparable to the best commercial wrought stainless steels and an improved creep strength compared with all the various grades of cast irons used for diesel exhaust components

Technical Accomplishments and Progress

- **Life cycle modeling of advanced propulsion materials was undertaken with an initial first-year effort determining cost-effectiveness of CF8C+ cast austenitic stainless steel**
- **CF8C+ has been demonstrated successful in several high-temperature applications and so a life cycle assessment in terms of energy, economic, and environmental is consequential**
- **Several analysis levels were considered, starting with raw material cost and ending with component cost with due consideration of fuel savings due to lightweighting**

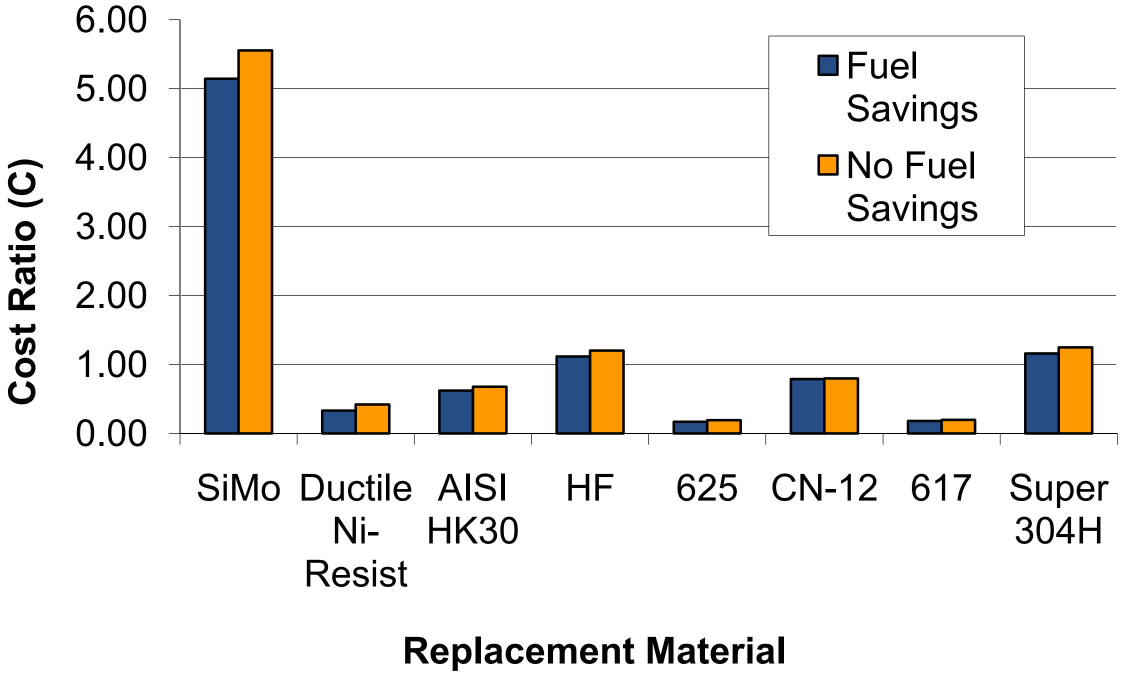
CF8C+ Savings Per Pound of Various Replacement Materials

- Mass savings estimated based on the same material bending stiffness
- Mass savings potential range is 0.01-0.18 per lb of replacement material, 18% max. savings with ductile Ni-Resist
- Most alloys cost significantly less, except SiMo, HF, and Super 304H; Cost savings range from \$0.67–\$10.10/lb
- Alloy 617 offers the most cost/mass savings potential; SiMo, HF, and Super 304H alloys are unfavorable

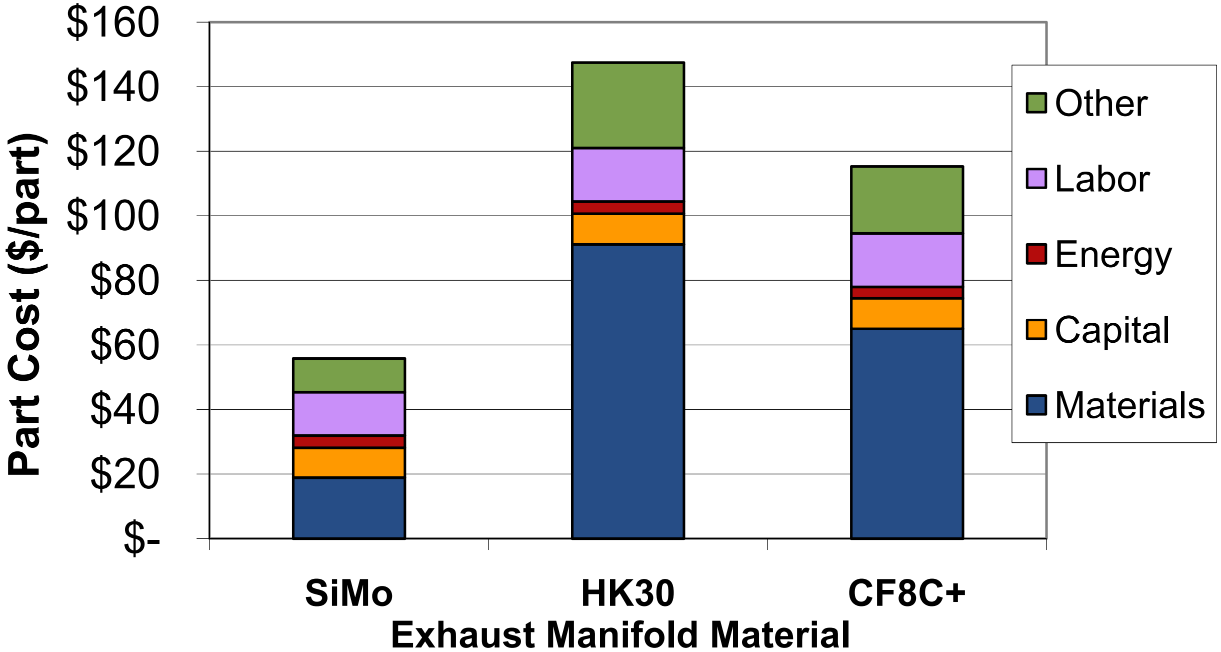
Alloy	Density (gm/cc)	Young's Modulus GPa	Alloy Cost (\$/lb)	Savings		
				Mass (lb)	Cost (\$)	Cost/ Mass
CF8C+	7.61	213	2.70	NA	NA	NA
Cast						
SiMo	6.67	148	0.45	0.07	-2.05	-27.7
Ductile Ni-Resist	7.37	140	5.24	0.18	3.04	16.5
HK30	7.53	186	3.67	0.08	1.19	14.7
HF	7.39	183	2.09	0.07	-0.42	-6.0
625	8.24	208	12.50	0.11	10.10	90.9
CN-12	7.52	213	3.33	0.01	0.67	46.2
Wrought						
617	8.03	211	12.50	0.08	10.02	122.2
Super 304H	7.72	200	2.01	0.07	-0.50	-7.1

Material Cost-Effectiveness Based on Fuel Savings

- Fuel savings estimate based on both primary and secondary mass savings per lb of replacement material
- Cost ratio is the ratio of CF8C+ material cost to replacement material (on per pound of replacement material basis) with and without fuel savings consideration
- Unfavorable cost ratios, i.e., greater than 1, were found in cases of SiMo, HF, and Super 304H
- Fuel savings consideration improves the cost competitiveness of CF8C+ by about 10% in case of alloy 617

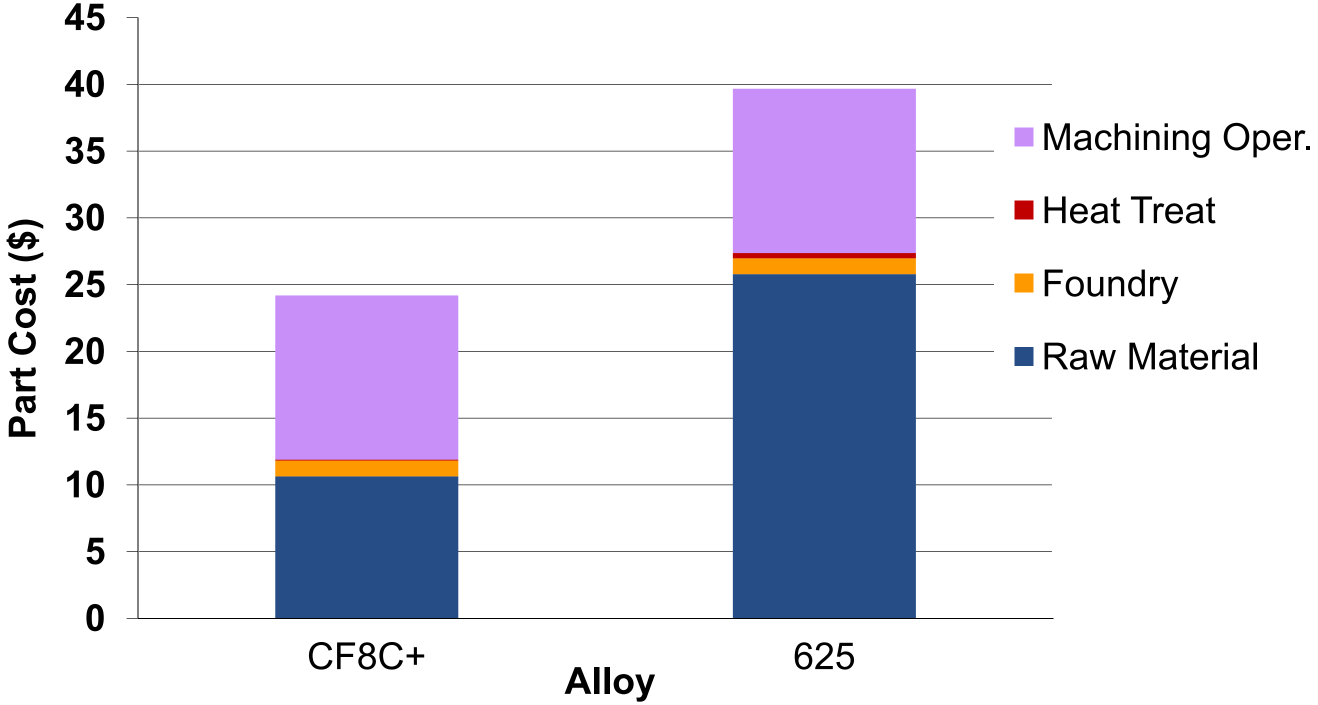


Cost-Effectiveness in Component Application 1



- **Competing materials—SiMo and HK30—considered for a 19-lb light-duty vehicle exhaust manifold application assuming high-volume automated green sand casting technology and the process cost modeling approach**
- **Raw material contributes a major share of total part cost – thus, least expensive material, SiMo, is the most cost-effective in this application**
- **Higher part cost of both stainless materials, i.e., HK30 and CF8C+, is due to labor-intensive finishing step and higher scrap rates**
- **Lower CF8C+ material cost facilitates lower part cost than HK30**

Cost-Effectiveness in Component Application 2



- **A 683-lb gas turbine case with 3" wall thickness based on centrifugal casting technology considered where nickel-based superalloys such as 617 and 625 are currently used**
- **Cost estimates are based on the major processing steps, i.e., raw material, foundry, heat treat, and machining operations**
- **40% CF8C+ part cost savings is anticipated due to**
  - **Lower raw material cost since stainless steel processing is same in both cases**
  - **Heat treatment savings (contributes only 2% of savings)**

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Proposed Future Work

- Energy savings analysis of CF8C+ cast austenitic stainless steel—ongoing
- Life cycle analysis of engine lightweighting in terms of downsizing vs. lightweight materials use—ongoing
- Viability of advanced propulsion materials in advanced powertrains such as hybrids and fuel cell vehicles
- Economic, energy, and environmental impact analyses from a life cycle perspective of advanced propulsion materials manufacturing technologies with an emphasis on aluminum, magnesium, titanium, and ceramics
- Advanced propulsion materials' potential in heavy-duty vehicles

Summary

- Development of advanced propulsion materials such as CF8C+ would provide cost savings in applications that require potential heat and corrosion resistant stainless steel or nickel-base superalloys
- It is important that cost-effectiveness of advanced propulsion materials be examined not only on the basis of material cost, but also as a component in specific potential applications, thus allowing consideration of manufacturing technology costs
- Cost of advanced propulsion materials remains a barrier, but weight savings and associated fuel savings along with processing cost benefits would allow it to be cost-effective as found in the case of CF8C+
- SiMo, HF, and Super 304H are the least favorable among the competing materials for CF8C+ considered here either due to a lack of cost savings and/or mass savings
- Fuel savings would allow an additional 10% cost savings, and CF8C+ application in exhaust manifold and gas turbine inner case appears to be favorable compared to HK30 and alloy 625, respectively