A Comparative Life Cycle Assessment of Cast Aluminum, Cast Iron, and Forged Steel Automotive Parts

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PROJECT GOALS

• Overall Goal
  – Compare emissions of greenhouse gases using the Life Cycle Assessment (LCA) technique for manufacturing, use and recycling/disposing of three automotive steering knuckles.
    • cast aluminum
    • cast iron
    • forged steel

• Objectives
  – Demonstrate a method that compares the environmental impacts during manufacturing using GaBi version 4.2 software (PE Group GmbH and IKP University of Stuttgart) and industry contacts
  – Standardize the use phase in such a way that only the difference in weights will effect greenhouse gas emissions
  – Provide an assessment of the environmental impacts created during the end-of-life (EOL) phase
  – Evaluate greenhouse gas emission during production, use, and EOL phases.
LIFE CYCLE ASSESSMENT PROCESS

- Processing
  - Production
  - Utilization
  - Recycling

- Specification
  - Technical
  - Economic
  - Ecological

- Balances
  - Materials
  - Waste
  - Energy
  - Emissions
  - Sewage

Impact assessment and valuation

Improvement
Forced steel  
SAE Grade 11V37  
steering knuckle of  
rear suspension of  
a 4-cylinder sedan

Cast aluminum  
ASTM A356-T6  
steering knuckle of  
front suspension of a  
6-cylinder minivan

Cast iron  
ASTM A536 Grade 65-45-12  
steering knuckle of  
front suspension of a  
4-cylinder sedan

2.5 kg weight  
2.4 kg weight  
4.7 kg weight

SCOPE

• Starting Points:
  – Cast Aluminum: aluminum ingot, thermal energy, and power grid
  – Cast Iron: ferrous scrap, thermal energy, and power grid
  – Forged Steel: steel billet, and power grid

• Ending Points:
  – Reclamation facility
  – Landfill site
• Steel scrap cycle is similar to cast iron scrap cycle
FORGED STEEL PRODUCTION

Modules circled are from GaBi database

Assumes scrap material input

EAF used in practice, but will compare with a BOF billet

Internally recycled - Flash scrap: 30%
Circled are from GaBi database

Machined scrap: 2%

- Same amount of cardboard packaging

- Same distances and trucks for transportation

Taken from GaBi 4.2, PE International
CAST IRON PRODUCTION PHASE

Internally recycled –
Gating scrap: 25%

Internally recycled –
Machined scrap: 10%

Taken from GaBi 4.2, PE International
CAST ALUMINUM PRODUCTION

Taken from GaBi 4.2, PE International

Assumes virgin aluminum input

Internally recycled – Gating scrap: 25%

Outside of scope - Machined scrap: 10%

Modules circled are from database of GaBi

Taken from GaBi 4.2, PE International
PRODUCTION CO₂ EMISSIONS

CML 2001, Global Warming Potential (GWP 100 years) [kg CO₂-Equiv]

- Die Cast Aluminum
- Sand Cast Iron
- Forged Steel (BOF)
- Forged Steel (EAF)

- Other
- Thermal energy from hard coal
- Power grid mix (forging)
- Power grid mix (cleaning)
- Power grid mix (sand casting)
- Power grid mix (heat treat)
- Power grid mix (installation)
- Power grid mix (machining)
- Power grid mix (die casting part)
- Cast iron part (sand casting)
- Aluminum ingot
- Steel billet
- Packaging (steering knuckle)
PRODUCTION NO$_x$ EMISSIONS

CML 2001, Global Warming Potential (GWP 100 years) [kg CO2-Equiv]

- Die Cast Aluminum
- Sand Cast Iron
- Forged Steel (BOF)
- Forged Steel (EAF)

- Other
- Thermal energy from hard coal
- Power grid mix (forging)
- Power grid mix (cleaning)
- Power grid mix (sand casting)
- Power grid mix (heat treat)
- Power grid mix (installation)
- Power grid mix (machining)
- Power grid mix (die casting part)
- Cast iron part (sand casting)
- Aluminum ingot
- Steel billet
- Packaging (steering knuckle)
PRODUCTION HALOGENATED EMISSIONS

CML 2001, Global Warming Potential (GWP 100 years) [kg CO2-Equiv]

- Other
- Thermal energy from hard coal
- Power grid mix (forging)
- Power grid mix (cleaning)
- Power grid mix (sand casting)
- Power grid mix (heat treat)
- Power grid mix (installation)
- Power grid mix (machining)
- Power grid mix (die casting part)
- Cast iron part (sand casting)
- Aluminum ingot
- Steel billet
- Packaging (steering knuckle)

Die Cast Aluminum
Sand Cast Iron
Forged Steel (BOF)
Forged Steel (EAF)
USE PHASE ASSUMPTIONS

- Weight is only changing variable

\[ F = \rho \frac{w}{W} \frac{M}{k} \]

\( F \) = fuel consumption (in kg fuel)
\( \rho \) = fuel density
\( w/W \) = steering knuckle wt (in kg)/vehicle wt (in kg)
(2.4 kg Al, 2.5 kg steel, 4.7 kg cast iron)
\( M \) = total vehicle mileage
\( k \) = vehicle fuel consumption per mile (kg fuel/mile)
USE PHASE

CML 2001, Global Warming Potential (GWP 100 years)

- Carbon dioxide from fuel consumption
- VOC (unspecified) from gas (regular) refinery
- Methane from gas (regular) refinery
- Halogenated organic emissions to air from gas (regular) refinery
- Sulphur hexafluoride from gas (regular) refinery
- Nitrous oxide from gas (regular) refinery
- Carbon dioxide from gas (regular) refinery

Basis: 1500 kg wt. car, 24 mpg, 125,000 miles

www.autosteel.org
END OF LIFE PHASE

Steel and Cast iron
99% of steel and iron is recovered

Aluminum
80% of aluminum is recovered
END OF LIFE EMISSIONS

CML 2001, Global Warming Potential (GWP 100 years) [kg CO2-Equiv]

- Die Cast Aluminum
- Sand Cast Iron
- Forged Steel

- Sulphur hexafluoride
- Nitrous oxide
- Carbon dioxide
- VOC (unspecified)
- Methane
- Halogenated organic emissions to air

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TOTAL LIFE-CYCLE EMISSIONS
(125,000 miles life-cycle)

CML 2001, Global Warming Potential (GWP 100 years [kg CO2-Equiv])

- Die Cast Aluminum
- Sand Cast Iron
- Forged Steel (BOF)
- Forged Steel (EAF)

- Recycle
- Use
- Production

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EFFECTS OF MILES DRIVEN ON TOTAL EMISSIONS

CML 2001, GWP (kg CO2 Eq)

- **Die Cast Aluminum**
- **Sand Cast Iron**
- **Forged Steel (BOF)**
- **Forged Steel (EAF)**

miles driven in lifetime

0 25000 50000 75000 100000 125000 150000 175000 200000

0 20 40 60 80 100 120

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SUMMARY AND CONCLUSIONS

The major factors of the greenhouse gas emissions are:

- Life-cycle impacts can be dominated by the use phase or production phase depending on the materials selected:
  - Aluminum steering knuckles were the lightest weight yet resulted in higher greenhouse gas production over the complete life cycle
    - Aluminum billet production has a large carbon footprint associated with electric production. Recycling would provide major benefits.
  - Cast iron steering knuckles were the heaviest of the parts studied and therefore the use phase was the major contributor to the greenhouse gases.
    - At life-cycles in excess of 175,000 miles, the cast iron steering knuckles had the highest greenhouse gas emissions.
  - The forged steel steering knuckle produced the least amount of greenhouse gasses under all use conditions.
    - EAF steel billets resulted in lower production emissions due to being scrap based versus BOF which contains scrap but is virgin iron based.
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