Update of Process Energy Requirement and Material Efficiency for Steel and Al Stamping in the GREET® Model

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ACRONYMS

AHSS	advanced high-strength steel
BIW	body-in-white
HSS	high-strength steel

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This memo documents the changes in the energy requirement and material efficiency for stamping of steel and aluminum in the GREET® model. These changes reflect the current status of stamping processes associated with vehicle production, and will be incorporated into GREET 2017.

1 ENERGY REQUIREMENT FOR STAMPING

Stamping is an important sheet metal forming process, especially for vehicle production. Ducker worldwide estimates that stamped steel parts comprise 40 wt% of an average light-duty vehicle on the North American market in 2015, while stamped Al parts account for another 2 wt% (Ducker Worldwide 2017).

In recent years, the energy consumption and material yield of stamping processes have received much attention. Table 1 summarizes reported energy intensity for stamping in literature, normalized to MJ per kg of part produced. Note that all reported energy consumptions are 100% electricity, since the press and its auxiliaries, as well as other equipment for loading, unloading, cutting, etc., are all powered by electricity. Also note that the value reported by Brown includes forming (0.30 MJ/kg) and cutting (0.36 MJ/kg); the value reported by Gao *et al* includes blanking (0.38 MJ/kg), forming (0.61 MJ/kg), cutting (0.38 MJ/kg), and handling (0.11 MJ/kg); whereas the value reported by Ingarao *et al* only accounts for the punch load of the press. The rest of the cited publications either report energy consumption for forming only, or do not specify processes included.

From Table 1, it can be observed that there is no substantial difference in the energy requirement for steel stamping and Al stamping. In fact, Al stamped panels are formed on the same presses as steel, with similar forming processes (Omar 2011a). Therefore, the same energy intensity will be used for steel stamping and Al stamping in GREET 2017. It can be also observed from Table 1 that stamping by hydraulic presses is more energy-intensive than by mechanical presses. Since both types of presses are used for vehicle production, and the ratio of parts produced by mechanical presses to those produced by hydraulic presses is not available, an energy intensity more representative of hydraulic presses will be used in GREET, as a conservative estimate.

It should be pointed out that, spring-back, the shape change of the formed panel upon lifting the die that can render the product out-of-tolerance, is a concern for Al stamping, and could therefore increase its energy requirement. High-strength steel (HSS) and advanced high-strength steel (AHSS) are also subject to spring-back (Omar 2011a). Since the penetration of stamped Al, HSS, and AHSS parts are expected to increase significantly over the next decade, the impact of spring-back on energy consumption by stamping should be revisited in future GREET updates.

Table 1. Reported Energy Consumption (MJ/kg part produced) for Stamping

	Brown 1996	Schuler 1998	Milford 2011	Ingarao 2012	Zhao 2015	Cooper 2017a	Cooper 2017b	Gao 2017
Stamping, Al	---	---	0.4[d]	0.03[b]	---	0.8[d]	0.24[d]	---
Stamping, steel	0.66[a]	0.8[d]	0.4[d]	---	0.65[d]	---	---	1.5[c]
Produced part	Generic vehicle parts	Generic	Door panel	Pyramid	Door	Hood	Tailgate	Half spherical
Press type	Generic	Hydraulic	Generic	Generic	Hydraulic	Hydraulic	Mechanical	Hydraulic

a. Includes forming and cutting
b. Represents the punch load only
c. Includes blanking, forming, cutting, and handling
d. Either includes forming only or does not specify included processes.

2 MATERIAL EFFICIENCY FOR STAMPING

Reported material efficiencies for stamping are summarized in Table 2. A more systematic study for steel stamping has reported by Omar (Omar 2011a). He evaluates the blanking area and the used surface area for the production of each body-in-white (BIW) component of a vehicle. The results show wide variance in the blanking-to-part material efficiencies for stamped BIW components manufacturing, ranging from 38% for body side outer, to 89% for front door outer panel. On a per part produced basis, the average material efficiency for BIW components stamping is 60%. On a per blanking area basis, the average material efficiency is 58% (Omar 2011a).

Table 2. Reported Material Efficiencies for Stamping

	Milford 2011	Ingarao 2012	Cooper 2017a	Gao 2017
Blanking	90%	N/A	80%	N/A
Stamping, Al	72%	55%	65%	N/A
Stamping, steel	68%	N/A	N/A	72%
Part	Door panel	Cone and pyramid	Hood	Half spherical

Note that the stamping process generally consists of blanking, stamping (hereinafter referred to as forming to avoid confusion), and potentially assembling practices (Omar 2011a), so the material efficiency for the entire stamping process should be the product of the material efficiency of each of the included sub-processes. It should be pointed out that Al stampings have a higher rejection rate than their steel counterparts, because of the low n-value (work hardening exponent, an indicator of the relative stretch formability, and the increase in strength as a result of plastic deformation for sheet metals), and narrower deformation window (an indicator of the formability for sheet metals) of aluminum (Omar2011b). However, as the values reported in literature do not exhibit considerable differences between the material efficiency of Al stamping and that of steel stamping, the same material efficiency will be used for both in GREET.

3 RESULTS

Based on the values reported in literature, the energy intensity for stamping is estimated to be 1.0 MJ/kg (0.860 mmbtu/ton) for both steel and Al, to account for energy consumption for other peripheral processes, such as blanking, cutting, and handling. The consumed energy is assumed to be 100% electricity.

The material efficiency for stamping is estimated to be 54% (90% for blanking, and 60% for forming) for both steel and Al. However, the loss factor in GREET is defined as follows:

$$Loss\ factor = \frac{Material\ embodied\ in\ product + Recycled\ scaps}{Material\ input}$$

The cut-off materials associated with the stamping processes should be well-sorted and fully recycled within modern production facilities, e.g. Ford's F150 production (Ford 2016), therefore the loss factor for stamping is estimated as 1.

Table 3. Stamping Data for GREET

	Energy intensity (mmbtu/ton)	Energy share	Loss factor
GREET2 2016	5.453	79% natural gas, 21% electricity	1.340
GREET2 2017	0.860	100% electricity	1.000

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