Chapter 3
History and Future Outlook of Hot Stamping

Eren Billur, Göran Berglund and Tord Gustafsson

Abstract Hot stamping can be traced back to traditional Japanese sword making techniques of thirteenth–fourteenth centuries [1]. The earliest patent about "Preßhärten" (Press hardening) was granted in 1914 in Switzerland. The technique described in this patent has been used in agricultural products since 1930s [2]. Hot stamping, as we know it today differs from these applications since the quenching is done at the press die to reduce distortion. Although hot stamping has been commonly used since early to mid-2000s, the beginning was in 1970s.

3.1 Early Developments: 1973–1990

Hot stamping was developed in Luleå, Sweden by Norrbottens Järnverks AB (Norrbotten Iron Works), in 1970s. The first patent application was completed in 1973 and was issued on November 2nd, 1977 [3]. In 1975, Swedish National Board for Technical Development (STU) funded a 6-year project at Luleå University of Technology (LTU) together with Volvo Trucks and Norrbottens Järnverks [4].

The group headed by Prof. Krister Källström built a number of research tools. These included several simple dies such as the flat hardening die, deep drawing die, and channel forming die as shown in Fig. 3.1. The next step was to produce a real part, and for research purpose, a hinge geometry was selected, Fig. 3.2.

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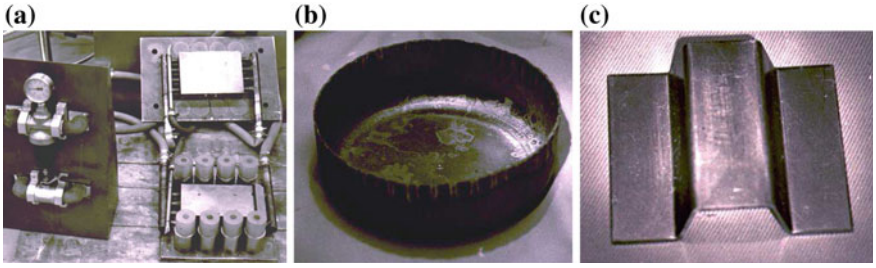

Fig. 3.1 Several research tools at LTU: **a** Flat hardening die, **b** deep drawing and **c** channel forming [4]

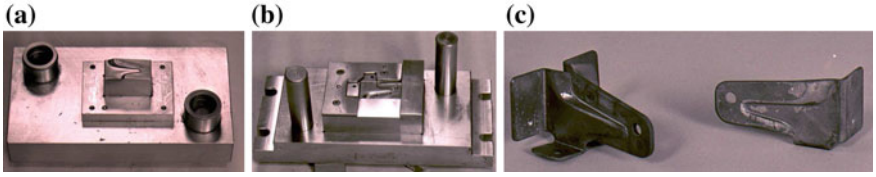

Fig. 3.2 Hinge halves: **a** upper and **b** lower die, **c** sample parts [4]

Fig. 3.3 Various geometries to study formability: **a** Stretch flanging, **b** Curved flange, **c** Stretching [4]

Together with Volvo Trucks, additional 6 dies were produced. These included several flanging dies emulating different geometries as shown in Fig. 3.3. Later, real parts such as gas tank brackets, bumper beams and cross member pieces were also produced, see Fig. 3.4. Some of these components were further tested for performance (load test, fatigue test, etc.) [4].

In 1978, while the studies were still continuing at Luleå University of Technology (LTU), Norrbottens Järnverk was merged with Domnarvets Järnverk and Oxelösunds Järnverk to form SSAB (Svenskt Stål AB, Swedish Steel) [5].

The first mass production hot stamping die—shown in Fig. 3.5—was made for Norbergs Spad- och Redskapsfabriker AB (Norberg Spades and Tools Plant). The cast iron die was designed for forming and quenching 1.5 mm thick spade. The cycle time was 20 s. This first mass production die was used for producing at least 20.000 parts.

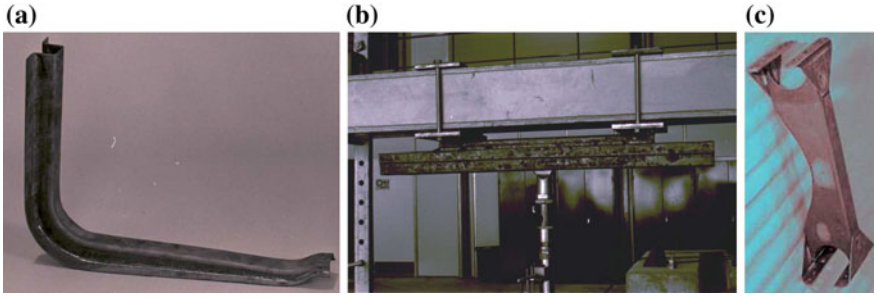

Fig. 3.4 Volvo Trucks prototype parts: **a** gas tank bracket, **b** bumper beam under load test, and **c** cross member piece [4]

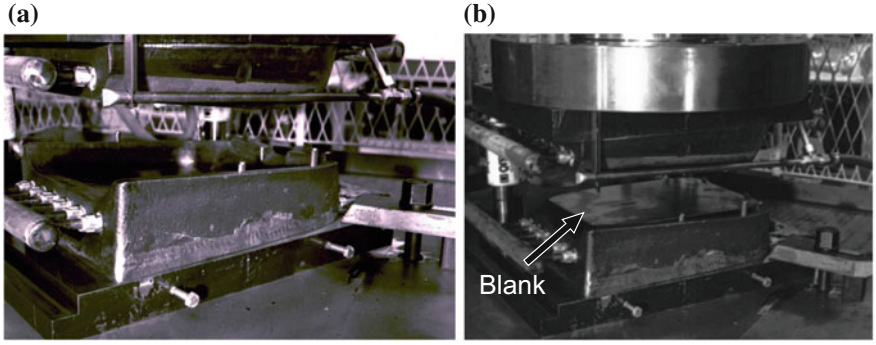

Fig. 3.5 First production tool for Norberg spade company [4]

Fig. 3.6 1984 Saab 9000 was the first automobile to have hot stamped side impact door beams [image from http://wikipedia.org]

Table 3.1 Advantages and disadvantages of AlSi-coated boron steels [17]

Advantages	Disadvantages
No scale formation (reducing one manufacturing step)	High material cost, compared to uncoated blank
Atmosphere controlled furnace is not needed	Cold-forming (indirect hot stamping) is impossible
Some corrosion protection	Heating system has to be accordingly (longer furnaces)

In 1982, the rights for hot stamping were sold to Plannja AB. The first application in automotive industry was in 1984, when Saab started buying hot stamped side impact door beams for Saab 9000, Fig. 3.6. In 1986, Jaguar also started using hot stamped door beams in its XJ model [6–10].

3.2 Further Developments 1990s

In 1991, Ford decided to use hot stamped door beams in its new middle class sedan, which was produced both in North America (Ford Contour/Mercury Mystique) and Europe (Ford Mondeo). The production for this car has started in 1993. Until 1995, Plannja AB was the only manufacturer of hot stamped products. However, as the patent rights expired in 1995, the competition started and many other companies started investing in hot stamping [6, 10].

Until the mid-90s, the hot stamped automobile components were only limited to side impact beams. In 1996, Renault facelifted its flagship model Safrane. The Phase II Safrane had a hot stamped bumper beam [11, 12]. In 1997, SSAB HardTech (the new name of the Plannja HardTech AB), together with Saab, applied for a patent to manufacture B-pillar reinforcements by hot stamping [13, 14].

In 1998, Volvo introduced the S80, equipped with a hot stamped rear bumper reinforcement [15]. Ford Focus I also introduced in 1998 had a hot stamped front bumper beam [8, 14]. In the same year, SSAB HardTech opened its first hot stamping line in the US (Mason, MI) [6].

3.3 Coated Blanks and Increased Usage: 2000s

In 1998, the French steel supplier Usinor (later merged to Arcelor) developed the aluminum-silicon-coated 22MnB5 steel, USIBOR 1500 ® [11, 16]. According to [17], the advantages and disadvantages of coated boron steels are given in Table 3.1. Figure 3.7 shows how uncoated blanks had scaling on their surfaces [18].

Fig. 3.7 VW Passat transmission tunnel stamped using: **a** uncoated blank causes scales; **b** coated blank has no scale problems [18]

In 2000, another French company, Sofedit started manufacturing hot stamped parts for the automotive industry. The same year (2000), BMW started using 3 mm thick A-pillar reinforcements in the new 3 series convertible. The parts were supplied by Benteler and were uncoated (Fig. 3.9). This was the first application of hot stamped steel at BMW [19–21].

In March 2001, Renault Laguna II (SOP 2001) was introduced which was the first car to receive 5 stars from EuroNCAP tests and had several components hot stamped. Figure 3.8a–c shows the manufacturing steps of the bumper beam of Laguna [16, 22] (Fig. 3.9).

In the same month, the new Citroën C5 was rolled out which had hot stamped A-pillar reinforcements from Sofedit. It is important to note that two A-pillars were produced from one blank and later laser trimmed, as shown in Fig. 3.8d–f. According to [23], this was the first use of hot stamped components in PSA (Peugeot-Citroën) Group. Parts of Citroën C5 and bumper beam of Renault Laguna II were also the first AlSi-coated hot-formed steels used in a car body [16, 24].

In April 2001, Peugeot 307 was introduced. This vehicle had hot stamped A and B-pillar reinforcements and rear bumper beam, accounted for 3.4% of the mass of the body in white. Contrary to PSA group's Citroën C5, all the hot stamped components in this vehicle were uncoated. One reason behind this selection could be the relatively higher production volume of 307 (2700 vehicles/day) compared to C5 (950 vehicles/day) [22–24].

In 2002, Volvo introduced its first SUV, XC90. This was a breakthrough, as 7% of the body-in-white was hot stamped, see Fig. 3.16. A total of 10 parts were hot stamped: 2 B-pillars (left and right), 4 door beams, roof rail, rear bumper beam, back panel, and rear seat frame [26, 27].

In 2003, Gestamp started prototype hot stamping work. The same year, Sofedit was acquired by ThyssenKrupp. By 2004, there were 4 big players in the market: Benteler, ThyssenKrupp Sofedit, Gestamp, and SSAB HardTech. In late 2004, VW became the first OEM to have an in-house hot stamping line, around the same time, SSAB

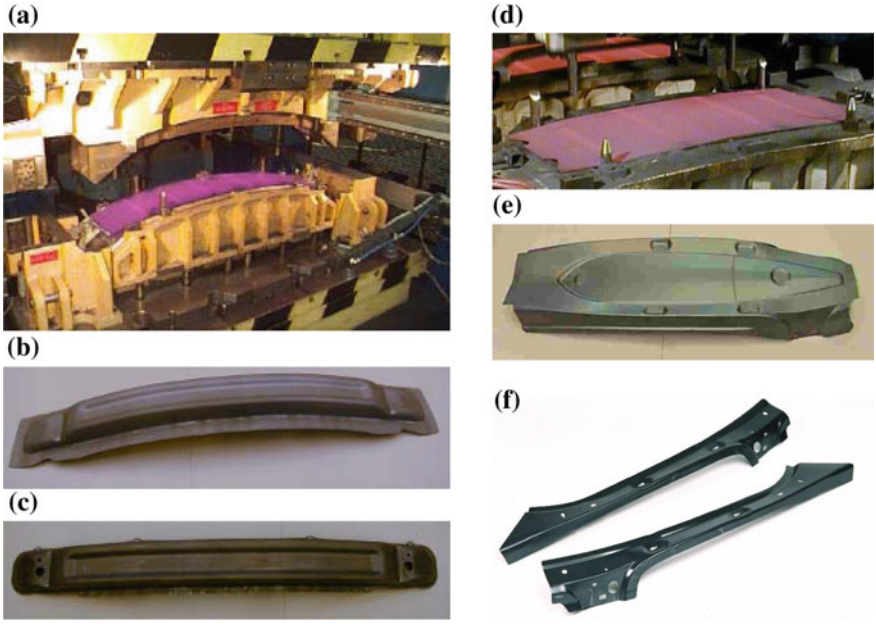

Fig. 3.8 Parts produced by Sofedit: **a–c** bumper reinforcement for Renault Laguna II (SOP 2000), **d–f** A-pillars for Citroën C5 (SOP 2001) [16, 25]

Fig. 3.9 One of the earliest examples of A-pillar reinforcement in BMW 3 Convertible (E46, SOP 2000) (Image re-created from [19])

Fig. 3.10 Hot stamped boron steel components in Passat B6 (SOP 2005) [30]

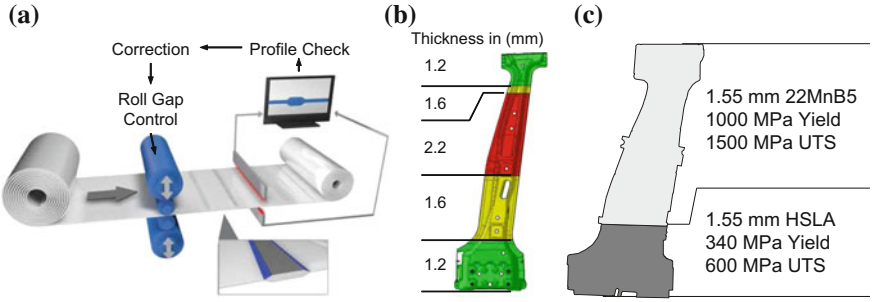

Fig. 3.11 **a** Tailor Rolling process [image courtesy of Mubea Tailor Rolled Blanks GmbH], **b** BMW X5 (SOP 2006) was the first car to have a tailor-rolled + hot stamped component [34], **c** Audi A5 (SOP 2007) had a tailor-welded b-pillar (re-created after [33, 35])

HardTech was acquired by Gestamp. In 2005, Magna Cosma started hot stamping [7, 21, 28, 29]. In 2005, VW rolled out the new Passat (B6) which had 19% hot stamped components in body-in-white. As shown in Fig. 3.10, the transmission tunnel and subplate were also hot stamped, which were both first time in the industry [9, 18, 30].

In 2006, Dodge Caliber and BMW X5 became the first cars to have tailor-rolled, hot stamped B-pillars [31]. According to [32] the tailor-rolled blank (Fig. 3.11a, b) saved 4 kg (9 lbs.)/vehicle in BMW X5. The tailor-rolled blank was supplied by Mubea and hot stamped at Benteler. In 2007, Audi A5 was built using tailor-welded transmission tunnel, B-pillars (Fig. 3.11c), and rear rails, all blanks were supplied by ThyssenKrupp Tailored Blanks [33].

3.4 Further Uses of Hot Stamping: 2010s

Beginning with 2010, most carmakers—including but not limited to: Alfa Romeo, Audi, Bentley, BMW, Chevrolet, Chrysler, Citroën, Dodge, Fiat, Ford, Honda, Jaguar, Jeep, Land Rover, Mazda, Mercedes, Nissan, Opel, Peugeot, Porsche, Renault, Rolls-Royce, Saab, Seat, Škoda, Toyota, Volkswagen, Volvo—had already started using

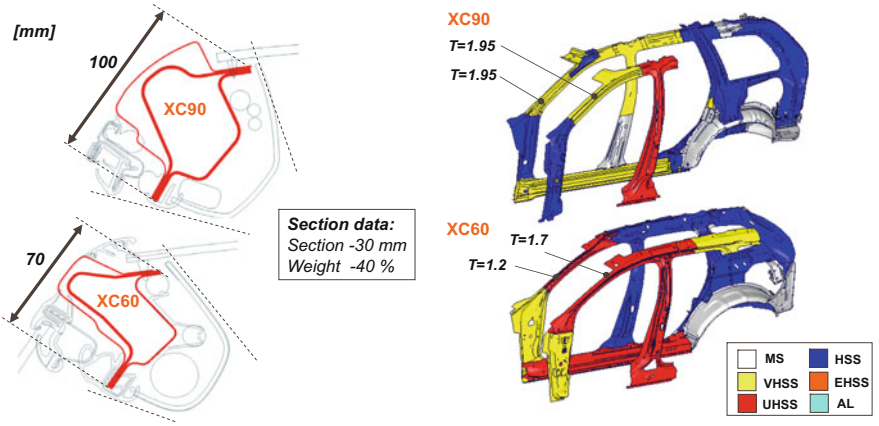

Fig. 3.12 Hot stamping not only saves weight (by decreasing the sheet thickness) but also improves visibility [41]

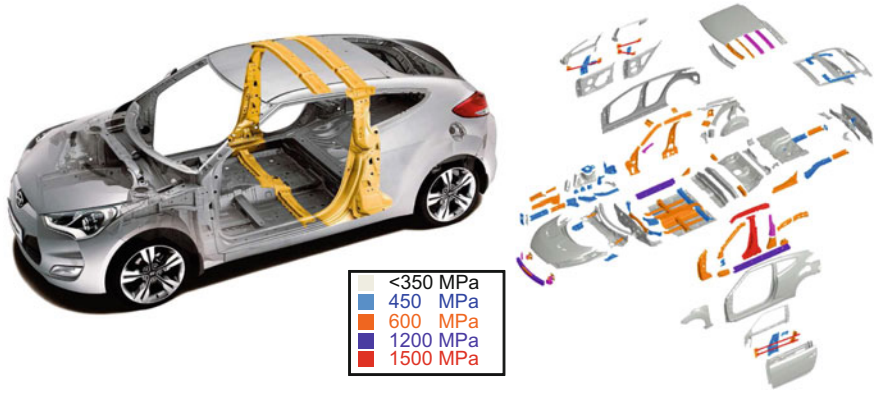

Fig. 3.13 2011 Hyundai Veloster's B-pillars are not in the same plane. This design was possible with use of hot stamped steels [51, 52]

hot stamped components in bodies-in-white or hang-on parts [8, 19, 20, 23, 33, 36–39].

As the technology advanced, hot stamping was not only used to reduce the weight of components, but new uses were found. The first was to make thinner pillars for improved visibility. Currently Ford Fiesta (SOP 2008), Jaguar XF (SOP 2008), Volvo XC60 (SOP 2008), BMW 5-series (SOP 2010), Opel Meriva (SOP 2010), Audi A6 (SOP 2011), and Subaru Impreza (SOP 2014) use hot stamped A-pillars specifically to reduce the width of the A-pillars to further improve the driver's vision. Figure 3.12 shows how hot stamped A-pillars improved the visibility in XC60 compared to 1st generation XC90 (SOP 2002). The new design also saved 5 kg (11 lbs.)/vehicle [40–46].

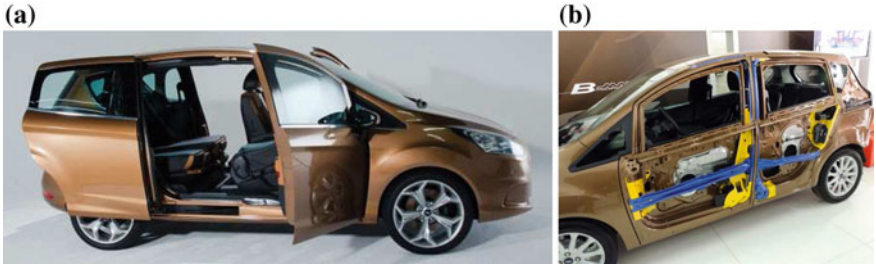

Fig. 3.14 2012 Ford B-Max: **a** showing the pillarless entry, **b** showing the hot stamped reinforcements (blue color) in both front and rear doors [54]

Many convertible vehicles (e.g., VW Golf Cabrio), even including high-end mostly aluminum ones (e.g., Ferrari California, Mercedes SLS-AMG and SL) have ultra high-strength steel reinforcements in their A-pillars to confirm with the rollover requirements [47–50]. As discussed, the first application of a hot stamped A-pillar was also a convertible BMW (Fig. 3.9).

Hot stamped boron steels allowed vehicle manufacturers to design unusual vehicles. One example to this was 2011 Hyundai Veloster. The vehicle was a 3-door coupe where the B-pillars are not one the same plane. This is because in the passenger side, there is a rear door whereas in the driver side there is not, Fig. 3.13 [51].

Another unusual design is seen in Ford B-Max (SOP 2012), a small van for European market. The car has a sliding rear door, but what makes it unique is that the car does not have a B-pillar (Fig. 3.14). The B-pillar was integrated in front and rear doors by using hot stamped boron steel reinforcements [53, 54].

Hot stamped steel is also used in hybrid and/or electric vehicles to protect the battery. The new "Range Rover" (SOP 2012) has an Aluminum intensive body-in-white but the hybrid version has boron steel battery protection which will allow it to "balance on a rock" without risk of battery damage [55]. Nissan Leaf (Electric Vehicle) on the other hand has AHSS battery cover [56]. The city car shown in Fig. 3.15, Chevrolet Spark (SOP 2009), had no martensitic or hot stamped (press hardened) steel in its body-in-white. The electric version of this vehicle is introduced in 2013 and had 14% hot stamped components by mass to protect the batteries [57].

3.5 Summary of the 40 Years

Figure 3.16 shows the mass percentage of hot stamped boron steel usage in several vehicles in the last decade. In this figure, only the highest usage of boron steel up to that year is listed. As explained earlier, Volvo XC90 and VW Passat were the first two breakthroughs in using hot stamped components.

Since 2012, several vehicles have surpassed 20% (by mass) barrier of hot formed body components. The first one was Volvo V40 (SOP 2012) with 20% hot stamped

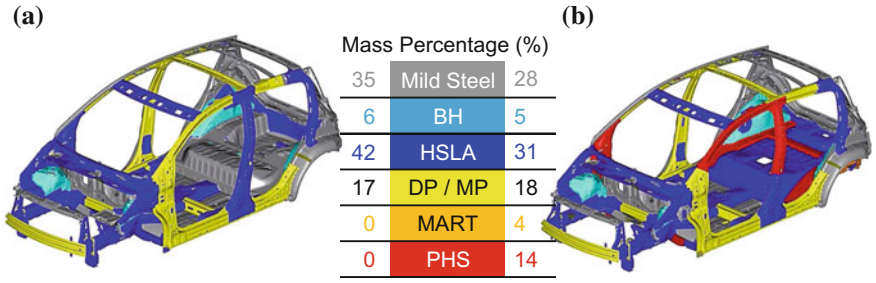

Fig. 3.15 Chevrolet Spark: **a** standard version does not have any hot stamped component, **b** electric version's body has 14% by mass hot stamped components (re-created after [57])

parts by mass [58]. Later on several Volkswagen Group vehicles on MQB platform were introduced; these vehicles typically had 24–28% of hot formed body by mass. These vehicles include, but are not limited to, Audi A3 (3rd generation), VW Golf 7, VW Passat B8, Seat Leon Mk3 and Škoda Octavia Mk3 [59]. However, since 2014, the highest usage of hot formed steels is in Volvo XC90 (2nd generation, production started in 2014), which accounts for 38% of the body mass [58].

As hot stamped parts found more applications in auto-body, more vehicle manufacturers adopted the technology. Figure 3.17 shows the increasing demand and future forecast of hot stamping industry. Note that, initially the technology was only used for simple parts, such as side impact door beams. With improvements in the

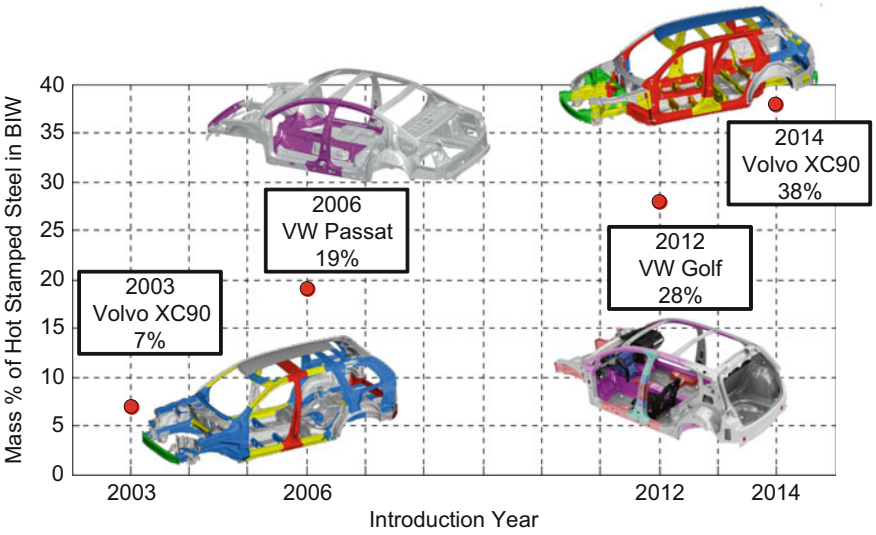

Fig. 3.16 Highest mass percentage of boron steels in automobiles by years (re-created after [9, 59–63])

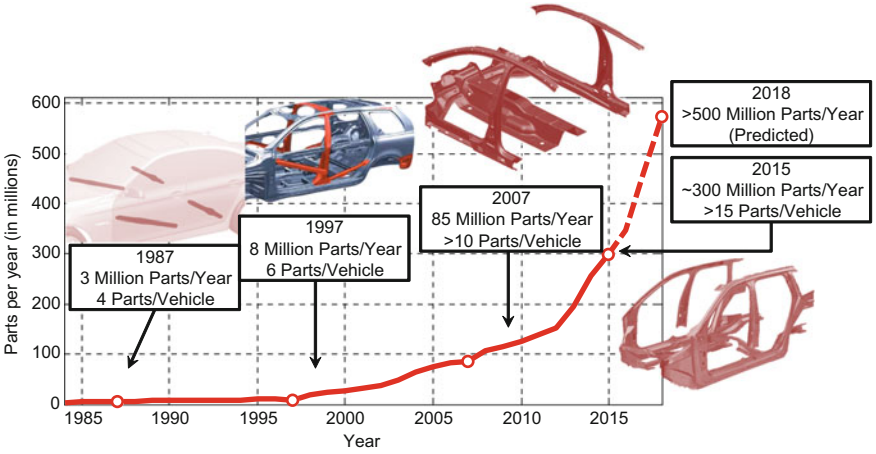

Fig. 3.17 Since its inception, both the complexity and production volume of hot stamped parts have been increasing (re-created after: [6, 44, 64–66])

technology, it has been used for transmission tunnels and subplates using tailored technologies. Currently, door rings and parts that are longer than 2 m (78 inches) can be hot formed [58, 67].

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