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Hydraulic concrete as a deep-drawing tool of sheet steel

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Abstract

To maintain the competitiveness of their products, sheet-steel manufacturers have to offer new technical innovations to reduce the costs of forming car bodies to their clients. In the current industrial process, the reduction could occur at the stage of manufacturing the deep-drawing tools used to produce about 20 to 50 prototype cars. These tools usually are made in polymer resin concrete covered by a gel coat. The use of high-performance hydraulic concrete allows us to markedly reduce production costs and simplify the process. Four types of gel-coat/concrete interfaces were tested. The best set of tools was tested on a deep-drawing line, which was able to deep-draw 16,000 parts and showed that hydraulic concrete tools covered by a gel coat can be used to produce prototype cars. Moreover, we can expect to extend their use to the production of small series of standard cars (10,000 to 20,000 parts).

Keywords: High-performance concrete; Surface layer; Mechanical properties

In the car industry, steel has always been the main material used. Nevertheless, every day, new materials are created and, to preserve the monopoly, the sheet-steel manufacturers have to offer new technical innovations to reduce the costs of forming sheet steel to the car manufacturers. In the entire industrial process ranging from the plans to the production of a standard car (Fig. 1), the reduction could occur at the stage of manufacturing deep-drawing tools used to produce prototype cars. Indeed, to conceive a new car, it is necessary to produce 20 to 50 prototype cars, because only the assembly of a prototype car is able to detect interference between the different deep-drawing parts and define the final shape of the parts. Moreover, these cars will be used in numerous tests, such as painting tests or crash tests. These tools usually are made of polymer resin concrete (PRC) covered by a gel coat, which is a metal charged resin. When the parts need a severe deep-drawing involving important stresses in the tools, the tools are machined in a metal charged epoxy resin. The production costs of a prototype car, considering the low number of units produced, is very high, about $200,000.

We proposed [1] to reduce the production costs of prototype tools by using hydraulic concrete in place of the PRC. Indeed, the automobile toolmakers have been used to produce tools in PRC, because the performances of hydraulic concrete were markedly lower several decades ago. Recently, better knowledge of the components, addition of fine elements such as silica fume [2], use of plasticizers and then of superplasticizers [3], and improvement of the packing density of solid particles [4] have improved the performances of hydraulic concretes. The subject of this paper is to show that the use of high-performance hydraulic concrete instead of PRC is an interesting way to reduce production costs. Therefore, different interfaces between concrete and gel coat were investigated and the best solution validated in an industrial deep-drawing line.

1. Deep-drawing technique

The body of a car contains more than 300 deep-drawn parts. Their sizes range from a few centimeters to more than a meter. In the scope of this study, we were interested in forming elements of large dimensions, such as doors, wings, or bonnets. Indeed, tools used to deep-draw such parts are voluminous, and concrete, due to its low bulk cost, is very competitive.

In the automobile industry, the most commonly used technique to deep-draw large parts is shown schematically in Fig. 2. The set is composed of three tools: the die, the punch, and the blank holder. Initially, the blank, which is a cut sheet steel, is put on the blank holder. At the beginning of the cycle, the die is lowered and the outer portion of the blank is gripped between the die and the blank holder. Then, the die, the blank holder, and the blank are lowered together and thus progressively wrap the blank around the punch. It

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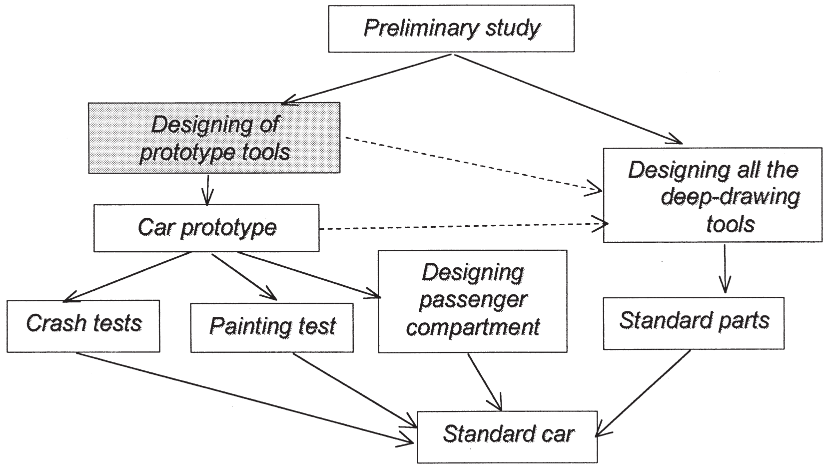

Fig. 1. Industrial process leading to the production of a standard car.

is the pressure in the die cushion via the pressure pins that controls the forming rate. Moreover, it is the pressure in the die cushion that controls the gripping force of the blank and, consequently, the swallowing rate of the sheet steel. At the end of the cycle, the die cushions are put under pressure again, which lifts the blank holder and ejects the formed blank from the punch. During a deep-drawing cycle, the tools are submitted to different kinds of stresses; the most important are compressive stress, confinement pressure, and friction stress due to sliding of the sheet steel on the tools.

2. Choice of materials

Until now, prototypes tools were made in PRC, which is siliceous sand melted in a polymer resin. When the deep-drawing is severe and induces considerable stresses to the tools, the molded PRC tools are replaced by machined metal charged resin tools. The performances of the metal charged resin are markedly better than that of the PRC (Table 1), its compressive strength is about 120 MPa, and its tensile strength is 24 MPa, whereas, for the PRC, these strengths are 30.7 and 9.1 MPa, respectively. Nevertheless, the metal charged resin is clearly more expensive, \$10,000/m^3 vs. \$800/m^3 for the PRC.

Usually, the PRC tools are coated with a 5-mm thick gel coat, which is also a metal charged resin. To decrease the production costs of the prototype tools, we suggested replacing PRC with high-performance hydraulic concrete (HPC). Although it is possible to compose ordinary concrete with the same compressive strength at 28 days as PRC, we have chosen HPC to keep the same production rate. Indeed, the period of time between the production and the use of the pro-

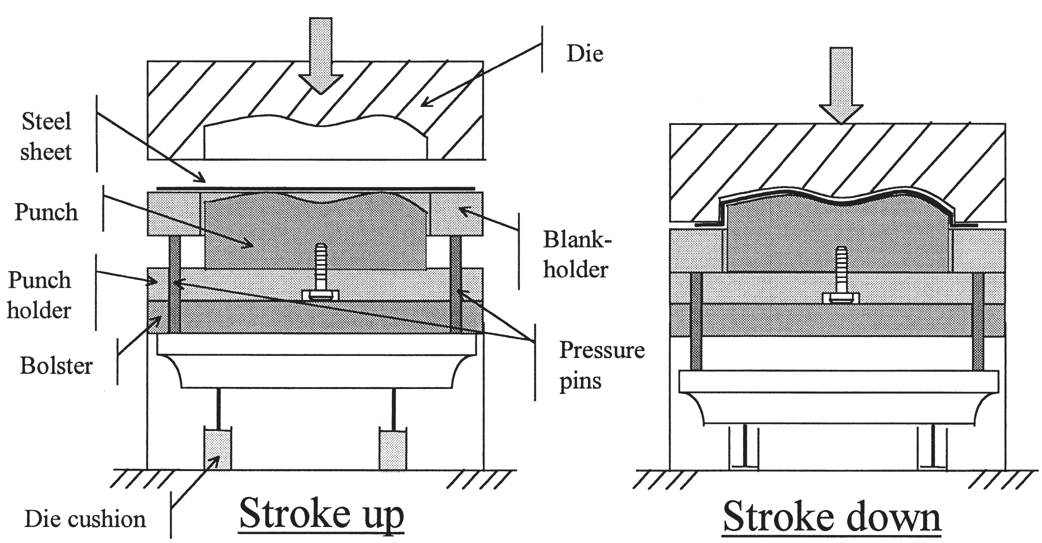

Fig. 2. Single-action press.

Table 1
Comparison between the different materials

PRC	Metal charged resin	HPC
fc_7 = 30.7 MPa	fc = 122 MPa	fc_{28} = 85.7 MPa
ft_7 = 9.1 MPa	ft = 23.8 MPa	ft_{28} = 5.9 MPa
E = 12,000 MPa	E = 10,500 MPa	E = 50,200 MPa
Cost = $800/m³	Cost = $10,000/m³	Cost = $100/m3

totype tools is generally 3 days. After 3 days, the HPC has the same compressive strength as PRC. Consequently, an HPC solution permits us to replace PRC without delaying the process. Moreover, HPC is less expensive than PRC and is easier to handle. The composition of the HPC chosen and the chemical composition of cement are given in Table 2. The mechanical characteristics (Table 1) of HPC are the average of three measures.

Observations of the microstructure of HPC and PRC using a scanning electronic microscope explain the higher performances of HPC over PRC. PRC has a large porosity (Fig. 3). During mixing and placing, the resin, due to its high viscosity, does not fill all the gaps between the sand grains. Conversely, HPC (Fig. 4) is dense and compact.

3. Study of the interface between resin

Due to its mechanical characteristics, HPC is able to replace PRC. Nevertheless, during the deep-drawing cycles,

Table 2
Composition of HPC and chemical composition of the cement

Ordinary Portland cement	420 kg/m³
Water (W)	147 L/m³
Sand 0/1 mm	590 kg/m³
Sand 1/4 mm	143 kg/m³
Gravel 4/10 mm	1021 kg/m³
Silica fume (SF)	42 kg/m³
Superplasticizer (SP)	4.2 kg/m³
W/C	0.35
SF/C	10%
SP/C	1%
Cement	
SiO_2	23.40%
Al_2O_3	3.05%
Fe_2O_3	2.15%
CaO	67.40%
MgO	0.70%
MnO	—
TiO_2	—
P_2O_5	—
K_2O	0.15%
Na_2O	0.10%
SO_3	2.10%
S^{2-}	<0.01%
Cl^-	0.03%
Loss on ignition	0.90%
C	0.35%
Free CaO	0.65%
Insoluble residue	0.1%

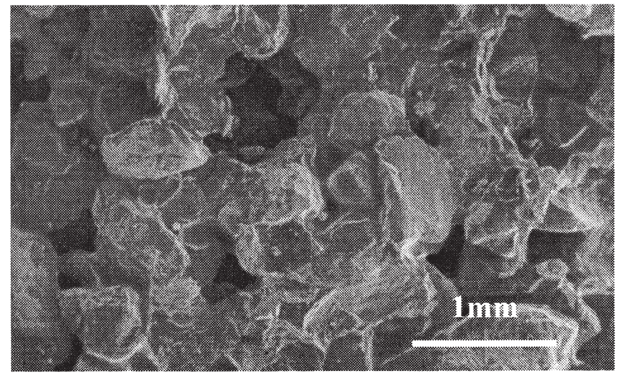

Fig. 3. Microstructure of the PRC.

the friction of sheet steel on the surface of the tools induced important stresses. To limit the abrasion rate of the prototype tools in PRC, they are covered with a gel coat. Because this gel coat has good results with PRC, we decided to apply this resin on HPC tools. However, to be most effective, the gel coat must adhere onto HPC perfectly. Therefore, four different interfaces between gel coat and HPC were investigated:

- Type I: an epoxy resin that is usually used as interface between PRC and gel coat;
- Type II: no interface; we cast the concrete directly on the fresh gel coat;
- Type III: a sand interface by projecting sand grains in the fresh gel coat;
- Type IV: a fiber interface by projecting fibers in the fresh gel coat; therefore, one end of the fibers is anchored in the resin and the other end of the fibers will be immersed in concrete.

The bond of the different interfaces was evaluated by three-point bending tests on 7 × 7 × 28-cm prisms (Fig. 5). The lower face of the prisms was coated. These tests showed that there is no significant difference between the tensile strengths (Table 3) of the four interfaces; all the values range between 6.3 and 7.3 MPa. The observation of the

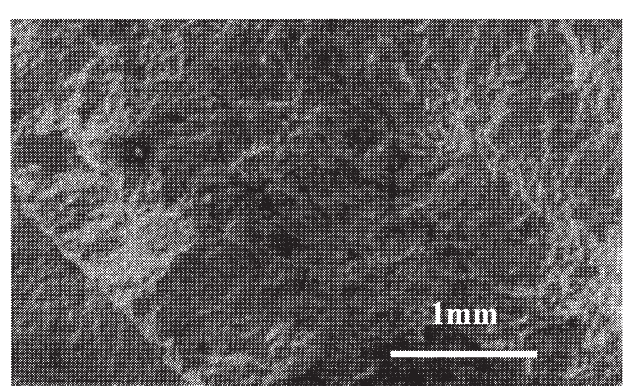

Fig. 4. Microstructure of the HPC.

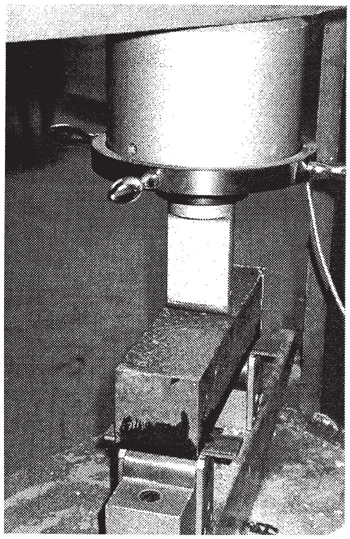

Fig. 5. Three-point bending tests of coated prisms.

broken prisms showed that, for the four kinds of interfaces, the bond between the concrete and gel coat was good. No macrocracks were observed at the interfaces.

Because there was no significant mechanical difference between the four interfaces, we retained the interface that was the most transposable in an industrial context. Indeed, to obtain a good bond between the surface resin and the HPC, the concrete should be cast quickly on the interface product for the type I interface and on the fresh resin for the type II interface, whereas for the type III and IV interfaces, when the sand grains or the fibers are sealed in the resin, we no longer need to cast the concrete immediately. Moreover, because the fibers are difficult to handle, we kept the sand interface.

The good bond of the type III interface was confirmed by observation under light-reflected microscopy of polished surfaces of the tested prism (Fig. 6). On the left of the figure, we can see the charged resin with metal particles (in white); on the right, there is the HPC. Between these two materials, the interface is composed of sand grains. The figure shows that the two materials are in intimate contact, which confirms the good bond of this interface.

4. Tests of the deep-drawing tools

To evaluate the performance of this composite, we produced a set of tools made of HPC covered by a gel coat

Table 3
Tensile strength and bond of the coated prisms

Interface	Strength (MPa)	Bond
Type I	6.6	Good
Type II	6.3	Good
Type III	6.3	Good
Type IV	7.3	Good

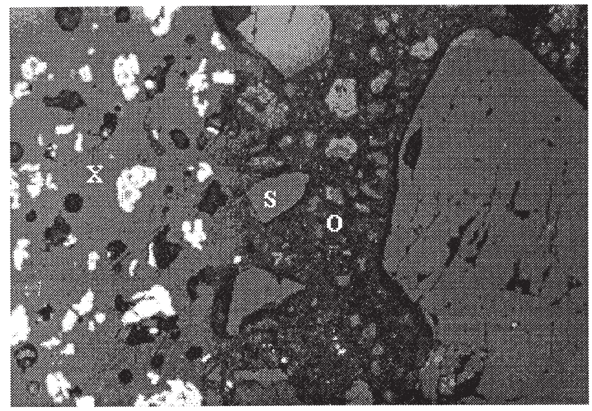

Fig. 6. Polished surface of the HPC/type III interface observed with a light-reflected microscope (X: gel coat, S: sand, O: HPC).

through a sand interface. The firm SOLLAC (Montataire, France) developed an industrial deep-drawing test used to evaluate the performances of tools made in different materials. In this test, the blank holder is made of cast iron and only the die and the punch are made of the tested material. These tools have small dimensions (Fig. 7), so we limit the size of the blank and, consequently, the steel consumption. The deep-drawing line (Fig. 8) is composed of a mechanical press fed by a steel coil. The rate of the deep-drawing test was about ome part every 3 s. The results of this test exceeded our expectations, because the punch, after 17,071 parts, presented no surface defect. It was the failure of the die gel coat, after 16,152 parts, which brought the test to a stop. Moreover, all the tools presented an important wear of the gel coat.

5. Conclusions

HPC is able to replace PRC for the production of deep-drawing tools. Indeed, the prototypes are used to deep-draw 20 to 50 parts, whereas the tests on the deep-drawing line showed that HPC tools covered by a gel coat are able to deep-draw more than 16,000 parts. The tests wqere stopped after failure of the gel coat. Consequently, HPC, which is eight times less expensive than PRC, is able to markedly reduce the manufacturing costs of prototype tools. Moreover, due to its low viscosity compared to PRC, the phases of mixing and placing are considerably simplified.

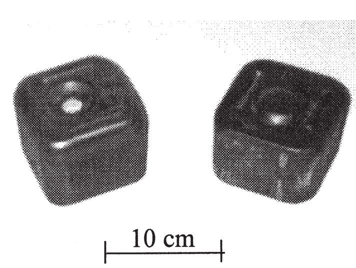

Fig. 7. HPC resin-coated die and punch.

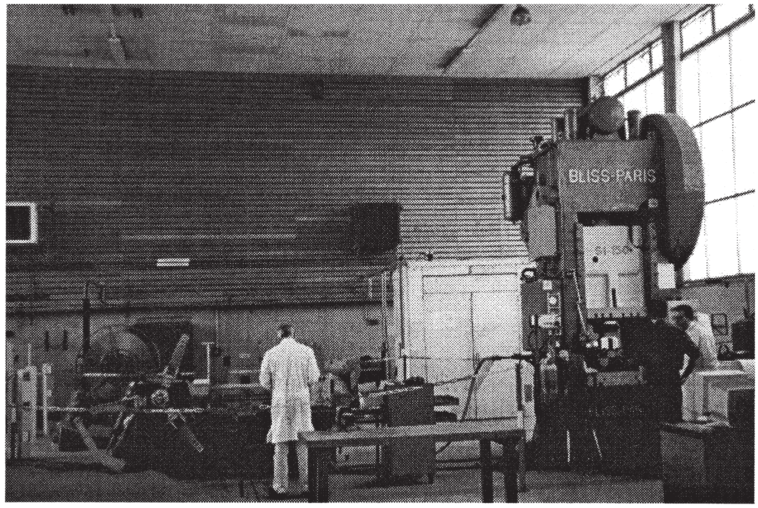

Fig. 8. Deep-drawing line.

6. Perspectives

The good behavior of the HPC tools showed that we can expect to reduce the production costs of prototype tools still further by suppressing the gel coat. Indeed, use of the gel coat is an additional step and complicates the production process.

If the good performances of HPC tools are confirmed on large parts, it will be interesting to extend their use to the production of small series of standard cars (10,000 to 20,000 cars). The car industry has reached the saturation point for large series, but new markets are emerging for specific cars produced in small or medium series. Until now, small or medium series involved only a few types of vehicles, such as limited edition cars, trucks, and luxury cars. However, the current trend shows that numerous other fields (electricians, plumbers, glass workers, etc.) are interested in commercial vehicles adapted to their needs. However, the standard tools currently used are made in cast iron, which involves important production costs and become profitable beyond one million cars. Conversely, PRC tools covered by a gel coat, due to their high rate of wear, are limited to the production of prototype cars. Therefore, HPC tools open new perspectives for car manufacturers, because they will be able to change their product range more often and to adapt their vehicles more rapidly to demand.

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