

Method for manufacturing a complex-formed component

The present invention relates to a method for manufacturing a multi-stage forming operation by very complex parts with austenitic materials by a combination of cold forming and annealing treatments. During the forming operation, the formation of twins have been achieved in austenitic materials ductility diminishes.

In car body engineering components with a complex forming geometry are manufactured with soft deep drawing steels. There are requirements to fulfil a higher strength lightweight, package or safety targets, available high strength steels like dual-phase steels, multi-phase steels or complex phase steels reach their limit of formability very often. The defined-adjusted mechanical values and microstructure parts (during steel-manufacturing) react sensitive to following forming or heat treatment steps during component manufacturing. Therefore they change undesirably their properties.

One solution are hot-forming operations like the so-called press-hardening, where heat-treatable manganese-boron steels are heated up to austenitization temperature (over 900°C), through hardening for a specific holding time and then formed at those high temperatures in a hot-forming tool to the resulting component. At the same time of the forming operation, the heat is discharged from the sheet to the contact areas of the tool und therefore cooled-down. The process is described for example in the US20040231762A1. With the process of hot-forming, complex parts can be realized by using a high-strength material. But the residual elongation is on a lowest level (most of the time <5%).

Therefore following cold forming steps are not possible as well as high energy absorption during a crash situation of a car body component. Furthermore not at any time, a tensile strength of 1,500MPa is requested, for example when the system becomes too stiff. Additionally the investment, repair and energy costs

as well as the necessary room for the roller head furnaces are very high with marginal cycle times in comparison to cold forming operations. Moreover the corrosion protection is on a lower level in comparison to coated cold-forming steels.

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For a lot of decades austenitic stainless steels are used in the application field of domestic goods for complex cold forming parts like sinks. The established materials are alloyed with chromium and nickel by using the hardening effect of TRIP (*TR*ansformation *I*nduced *P*lasticity) where the metastable austenitic
10 microstructure is changed into martensite during a forming load. At room temperature the austenitic microstructure is stable because of the lower martensitic starting temperature. In the literature this effect is well-known as „deformation induced martensite formation“. A drawback of using these materials for complex cold-forming operations is that the formally austenitic
15 material changes the properties to a martensitic microstructure with lower ductility, increasing of hardness and therefore a decrease of the resulting energy absorption potential. Furthermore the process is not reversible. The advantages of an austenitic material like the nonmagnetic properties get loss and cannot be used in the component situation of the material. The irreversible
20 microstructure change is a big drawback for complex multi-staged forming operations where the residual elongation is insufficient. Furthermore the effect of TRIP is sensitive to temperature which results in a further investment need for tool cooling. Moreover those materials show the danger of stress induced delayed cracking when changing their microstructure during a forming process
25 to martensite. The stacking fault energy of those materials with TRIP-effect is lower than SFE $< 20 \text{ mJ/m}^2$. Additionally the danger of hydrogen embrittlement is given by the martensite transformation.

The described austenitic stainless steels with TRIP effect are in initial state
30 nonmagnetic. The publication DE102012222670A1 describes a method for the local heating of components manufactured by stainless steels using the TRIP

effect and the out of this effect rising forming martensite. Furthermore equipment for inductive heating of austenitic stainless steels with martensite transformation is created by a recrystallization locally in the martensite areas of the component.

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The publication WO2015028406A1 describes a method to harden a metal sheet, whereat by shot peening or grit blasting the surface is hardened. As a result the surface is more scratch-resistant for sink applications. Especially the usage of metastable chromium-nickel alloyed 1.4301 is pointed out.

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The object of the present invention is to eliminate some drawbacks of the prior art and to establish a method for manufacturing of a complex-formed component of austenitic steel having non-magnetic properties at the end and during all process steps. The multistage process with a combination of forming and heating results in reversible material properties, which is achieved by TWIP hardening effect and the stable austenitic microstructure. The essential features of the present invention are enlisted in the appended claims.

The steel used in the invention contains interstitial disengaged nitrogen and carbon atoms so that the sum of the carbon content and the nitrogen content (C+N) is at least 0,4 weight %, but less than 1,2 weight %, and the steel advantageously can also contain more than 10,5 weight % chromium, being thus an austenitic stainless steel. Another ferrite former like chromium is silicium, which works as a deoxidizer during steel manufacturing. Further silicium increase the strength and hardness of the material. In the present invention the silicium content of the steel is less than 3.0 weight-% to restrict hot-crack-affinity during welding, more preferably less than 0.6 weight-% to avoid the saturation as a deoxidizer, further more preferably less than 0.3 weight-% to avoid low-melting phases on Fe-Si basis and to restrict an undesirable decrease of the stacking fault energy. In case the steel contains essential contents of at least one ferrite phase former, such as chromium or

silicium, a compensation with the contents of the austenite phase formers like carbon or nitrogen, but also such as manganese weight-% is between 10% and less than or equal to 26%, preferably between 12-16%, carbon and nitrogen both weight % values are more than 0.2% and less than 0.8%, nickel weight %
5 is equal or less than 2.5%, preferably less than 1.0%, or copper weight % is less or equal than 0.8%, preferably between 0.25 – 0.55 % will be done in order to have a balanced and sole content of austenite in the microstructure of the steel.

10 The present invention exists in that complex forming parts can be realized with a multi-staged cold forming and heating operation under retention or optimization of the austenitic material properties after finishing the forming operation.

15 The forming steps of the multi-staged process are carried out by hydro-mechanical deep-drawing processes like sheet-hydroforming or internal high-pressure forming.

Furthermore the forming steps of the multi-staged process are carried out by
20 deep-drawing, pressing, plunging, bulging, bending, spinning or stretch forming.

According to the present invention an austenitic steel with an elongation A_{80} is equal or more than 50% is used in a multi-staged forming process, whereby the
25 material is characterized by a TWIP (Twinning induced Plasticity) hardening effect, a specific adjusted stacking fault energy between 20 more than or equal SFE less than or equal 30 mJ/m², preferably 22-24 mJ/m² and therefore stable austenitic microstructure as well as stable nonmagnetic properties during the complete forming process.

The invention relates to a method for a multi-stage forming operation, where forming and heating are consisting by two different steps of operation, where multi-stage metal-forming process includes at least two different (or independent from each other) steps where at least one step is a forming step.

5 The other can be a further forming step or for example a heat treatment. Furthermore in the invention is described a subsequent process which includes forming and heating for creating complex formed parts and which uses to reach this target an austenitic (stainless) steel with TWIP hardening effect with its specific properties and possibilities for complex forming parts manufactured out
10 of austenitic steel with utilization of the TWIP (Twinning Induced Plasticity) hardening effect. During heating the twins in the microstructure of the used TWIP material are dissolved and during forming the twins in the microstructure of the used TWIP material are rebuilt.

15 Complex formed parts in state of the art for the sheet fabricating industry are white goods, consumer goods or car body engineering. Furthermore the extensive-designed and complex forming geometries have the benefit of saving number of parts, or integrating additional functions. A multi-staged complex-formed component as a white good can be found like a kitchen sink or bathes
20 in domestic appliances like a drum of a dish washer or washing machine. Furthermore functional or constructive requirements like package limitations e.g. longitudinal member of a car or volume specifications such as tanks, reservoirs are also suitable for a complex constructive configuration. Additionally design aspects e.g. sink or load path of crash structures such as
25 crash box with bumper systems for cars can be further solutions to the method of invention. Furthermore the invention is suitable for hang-on parts of transportation systems, like complex-formed doors or door-side impact beams, as well as for interior parts like seat structures especially seat back walls. The component deformed according to the present invention can be applied for
30 transport systems, such as cars, trucks, busses, railway or agricultural vehicles, as well as for automotive industry like an airbag sleeve or an fuel filler pipe.

The multistage forming operation is an alternating process of cold forming e.g. lower than 100°C and not under -20°C, but preferably at room temperature and following short-time heating. The number of process steps depends on the forming complexity.

The present invention is illustrated in more details referring to the attached drawings where

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- Fig. 1 shows hardness-comparison of different process,
- Fig. 2 shows the formation of twins as a metallographic inspection,
- Fig. 3 shows forming degree diagram of a an austenitic TWIP steel,
- Fig. 4 shows effect of hardening from a stamped edge,
- 15 Fig. 5 shows effect of surface hardening by shot peening,
- Fig. 6 shows effect of surface nitriding heat treatment on the mechanical properties of an austenitic TWIP steel, and
- Fig. 7 shows a multi-stage metal-forming process.

- 20 Fig. 1 shows the result of a hardness measured component after such a forming and heating operation. Hardness-comparison of different process steps of the multi-staged forming operation: Initial, base material (left), after first forming step with a forming degree of 20% (middle) and after heating process (right); for every state 10 hardness point per measured.

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In Fig. 2 the formation of twins is shown as a metallographic inspection in figure 2, related to the hardness measurement in figure 1.

- Fig. 3 shows the forming degree diagram of austenitic TWIP steel with 12-17% of chromium and manganese.
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In Fig. 4 is shown the effect of hardening from a stamped edge for a 12-17% chromium and manganese alloyed TWIP steel.

Fig. 5 shows the effect of surface hardening by shot peening on full-austenitic
5 TWIP steel.

In Fig. 6 is shown the effect of surface nitriding heat treatment on the mechanical properties of an austenitic TWIP steel in annealed condition $R_{p0.2}$ = yield strength, A_{80} = elongation after fracture, A_g = uniform elongation, sample
10 definition: A = sampled in initial annealed condition, N = sample after nitriding treatment.

In Fig. 7 a multi-stage metal-forming process consists of different heating and forming steps with utilization of the TWIP hardening effect.

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The material used in the method will be hardened during the forming operation because of the TWIP effect, but the material will maintain the austenitic microstructure. For an austenitic TWIP material the forming degree shall be less than or equal to 60%, preferably less than or equal to 40%. If the forming
20 potential, defined by the forming degree of the material is at the end of the method or if high tooling forces for forming are required, the second step, a heating step can be started. During the following heating step, the twins are dissolved and the material will be softened again. Because of the before defined material characteristics, the method is a reversible process. The
25 heating process can be integrated into one forming tool with induction or conduction. The heating temperature must be between 750 and 1150°C, preferably between 900 and 1050°C. The process can be repeated as many times as required to establish the desired complex geometry.

The initial thickness of the sheet used for the multi-staged process shall be less than 3.0 mm, preferably between 0.25 and 1.5 mm. It is also possible to use flexible rolled sheets with the present invention, too.

- 5 The component is in the form of a sheet, a tube, a profile, a wire or a joining rivet.

The formations of twins are shown as a metallographic inspection in figure 2, related to the hardness measurement in figure 1. The formation of twins by
10 forming and dissolving by heating can be pointed out very well. With a further forming step after heating, the formation of twins is restarted again and the component will be hardened again. This process can be used alternated and repeated as many times as required to reach the geometry as well as target mechanical values for strength and elongation. Therefore the last step of the
15 multi-staged forming operation can be a forming step with a defined forming degree as well as a locally heating step. For the use of a TWIP-steel which is alloyed with 12-17% of chromium as well as manganese, the forming diagram is used to adjust the sufficient values of the finished component, figure 3. As seen in figure 3, the invention is especially suitable for high or ultra-high
20 strength steels having a minimum yield strength level more or equal than 500 MPa. The heating steps can be designed with induction, conduction or also infrared technology. Heating-up rates of 20K/s are possible and do not influence the behavior of the twins.

- 25 Additionally forming operations can be integrated to the forming tool. As a result the hardening effect for state of the art operations can be reached over 160% of the base material. This drawback of edge hardening can be solved also by a following heating step. As a result the edge crack sensitive can be reduced significantly.

A further positive aspect of the invention is the possibility to create a compressive stress value on the surface by an upset forming operation such as shot peening, grit blasting or high frequency pounding to reduce edge crack or surface crack sensitivity as well as a better fatigue behavior when the multi-stage formed component is under fatigue stressed conditions e.g. automotive component. Such surface treatment is in general well-known but the combination with the pointed out material characteristic shows new properties because the microstructure and therefore the material properties (e.g. non-magnetic) will be constant. The combination of process and material results in the values are shown in table 1, where the effect of surface hardening (shot peening) and subsequent heat treatment are on the residual stress level of full-austenitic TWIP steels.

material	Yield strength	Residual stresses on the surface [MPa]		
	[MPa]	Initial state	After shot peening	After an subsequent heat treatment
TWIP steel	515	28	-811	-560
annealed condition				
TWIP steel	811	102	-889	-589
strain hardened				

Table 1

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In table 1, a plus sign means tensile stresses on the surface; a minus sign means a compressive stress level.

The general deviation of the measuring method can be +/- 30MPa. It can be shown with table 1. that the material stresses in initial state, especially for the strain hardened cold-rolled variants, can be transferred by an upset forming operation into uncritical compressive values. Such an operation can be also integrated into the multi-stage forming process because a high compressive load level can be also maintained after a subsequent heat treatment.

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A multi-staged complex-formed component can be used as an automotive component, like a wheel-house, bumper system, channel or as a chassis component e.g. suspension arm. Furthermore a multi-staged complex-formed component as a mounting part can be used in transportation systems like a
5 door, a flap, a flender beam or a load-bearing flank, a interior part of a transport system like a seat structure component e.g. seat backrest.

There are also possibilities to create a multi-staged complex-formed component as a part of a fuel injection system like a filler neck or as a tank or
10 storage for cars, trucks, transport systems, railway, agricultural vehicles as well as for automotive industry, and further in building and a pressure vessel or boiler or to be used of a multi-staged complex-formed component as battery electric vehicles or hybrid cars like a battery case.

An additional surface effect like an upset forming operation can be reached
15 with a nitriding or carburizing heat treatment. Both elements, nitrogen and carbon, operate as austenite formers and therefore this elements stabilize the local stacking fault energy and the resulting hardening effect, TWIP mechanism. The effect of nitriding or carburizing is in a hardening of the near surface structure of the component as shown in figure 5. Furthermore, the near
20 surface structure influence for the mechanical values of the TWIP steel, represent as shown the mechanical values in figure 6.

A nitriding or carburizing surface treatment with a heating temperature between 500 and 650°C, preferably between 525 and 575°C, is integrated into the multi-
25 staged process to create a scratch-resistance and at the same time non-magnetic surface of the component.

A multi-stage metal-forming process can be seen in figure 7, which includes a sheet, plate, tube 1 at least two different (or independent from each other)
30 steps where at least one step is a forming step 2. The next step 3 is heat

treatment. The number of multi-stage process 4 steps depends on the forming complexity 5. As a final result of the method is a complex-formed component 6.

Claims

1. A method for manufacturing a complex-formed component in a multi-stage process where cold forming at a temperature in the range of -20°C to 100°C and heating are alternated for at least two multi-stage process steps, the material being an austenitic stainless steel with TWIP hardening effect, whereby the steel has an initial elongation of A_{80} greater than or equal to 30%, the steel has a specific adjusted stacking fault energy SFE in the range 20 to 30 mJ/m^2 , and the forming degree is less than or equal to 60 % **characterized** in the temperature during the heating steps being in the range of 750°C to 1150°C so, that the material during every process step and a component produced has an austenitic microstructure with non-magnetic reversible properties.
2. The method according to the claim 1, **characterized** the initial thickness of the sheet used for the multi-staged process should be less than 3.0mm, preferably between 0.25 and 1.5mm.
3. The method according to claim 1 or 2, **characterized** in that the sum of the carbon content and the nitrogen content (C+N) in the austenitic steel to be deformed in more than 0,4% weight %, but less than 1,2 weight %.
4. The method according to any of the preceding claims, **characterized** in that the component is in the form of a sheet, a tube, a profile, a wire or a joining rivet.
5. The method according to any of the preceding claims, **characterized** in that the used material is a stable full-austenitic steel using the TWIP hardening mechanism with a defined stacking fault energy (SFE) in the range 22-24 mJ/m^2 .
6. The method according to any of the preceding claims, **characterized** in that the used material has an initial elongation A_{80} greater than or equal to 50%.

7. The method according to any of the preceding claims, **characterized** in that the used austenitic TWIP steel has a manganese weight-content between 10% and less than or equal to 26%, preferably between 12 and 16% manganese.

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8. The method according to any of the preceding claims, **characterized** in that the used austenitic TWIP steel is a stainless steel with more than 10.5% chromium, preferably between 12 and 17% chromium.

10 9. The method according to any of the preceding claims, **characterized** in that the forming steps of the multi-staged process are carried out by deep-drawing, pressing, plunging, bulging, bending, spinning or stretch forming.

10. The method according to any of the preceding claims, **characterized** in
15 that the forming steps of the multi-staged process are carried out by hydro-mechanical deep-drawing processes like sheet-hydroforming or internal high-pressure forming.

11. The method according to any of the preceding claims, **characterized** in
20 that heating temperature of the heating steps is at a temperature range of 900 to 1050°C.

12. The method according to any of the preceding claims, **characterized** in
25 that the heating steps of the multi-staged process are carried out by induction heating, conduction heating or infrared heating.

13. The method according to any of the preceding claims, **characterized** in that a forming process is integrated into the multi-staged process as a non-final step before a subsequent heating step.

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14. The method according to any of the preceding claims, **characterized** in that an upset forming treatment on the surface like shot peening, grit blasting or

high frequency pounding is integrated into the multi-staged process to create a scratch-resistant and compressive-loaded surface of the component, which is at the same time non-magnetic.

- 5 15. The method according to any of the preceding claims, **characterized** in that a nitriding or carburizing surface heat treatment with a heating temperature between 500 and 650°C, preferably between 525 and 575°C, is integrated into the multi-staged process to create a scratch-resistance and at the same time non-magnetic surface of the component.

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16. The use of a multi-staged complex-formed component manufactured by a method according to any of claims 1 to 15 as a white good like a kitchen sink or bathes in domestic appliances like a drum of a dish washer or washing machine.

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17. The use of a multi-staged complex-formed component manufactured by a method according to any of claims 1 to 15 as an automotive component like a wheel-house, bumper system, channel or as a chassis component (e.g. suspension arm).

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18. The use of a multi-staged complex-formed component manufactured by a method according to any of claims 1 to 15 as a mounting part for transportation systems like a door, a flap, a fender beam or a load-bearing flank, a interior part of a transport system like a seat structure component.

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19. The use of a multi-staged complex-formed component manufactured by a method according to any of claims 1 to 15 as a part of a fuel injection system, like a filler neck or as a tank or storage for cars, trucks or as a pressure vessel or boiler.

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20. The use of a multi-staged complex-formed component manufactured by a method according to any of claims 1 to 15 in battery electric vehicles or hybrid cars like a battery case.