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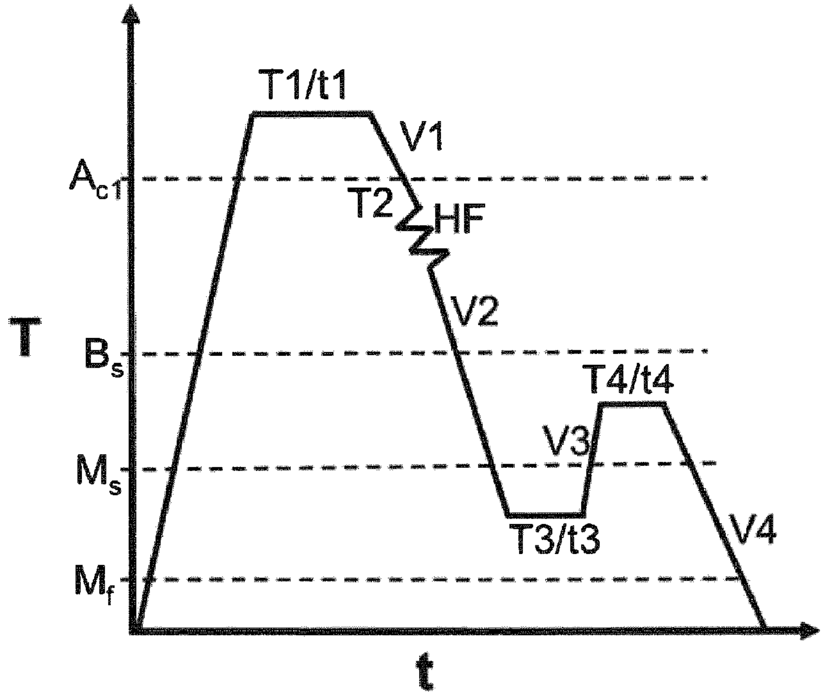

Figure 1

(57) Abrégé/Abstract:

The invention relates to a method for hot-forming a steel blank into an article comprising the steps of: a. heating a steel blank to a temperature T1 and holding the heated blank at T1 during a time period t1, wherein T1 is in the range of Ac1 to Ac3+200 °C and

(57) **Abrégé(suite)/Abstract(continued):**

wherein t1 is at most 12 minutes, b. transferring the heated blank to a hot-forming tool during a transport time t2 during which the temperature of the heated blank decreases from temperature T1 to a temperature T2, wherein T2 is above Ar1 and wherein the transport time t2 is at most 12 seconds, c. forming the blank in the hot-forming tool into an article and quenching it in the hot-forming tool from a temperature T2 to a temperature T3 at a cooling velocity V2 of 25 °C/s or more, d. isothermal holding the article at a temperature T4 for a time period t4, e. wherein temperature T3 and/or temperature T4 is between Ms and Mf and wherein t4 is more than 10 seconds and less than 10 minutes, f. cooling the article from temperature T4 to room temperature at a cooling velocity V4.20 The invention also relates to a hot-formed article obtained by the method.

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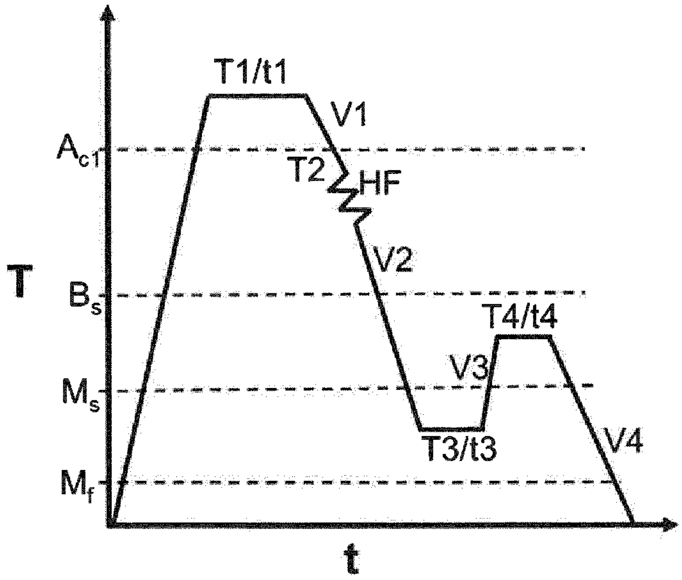

Figure 1

(57) Abstract: The invention relates to a method for hot-forming a steel blank into an article comprising the steps of: a. heating a steel blank to a temperature T1 and holding the heated blank at T1 during a time period t1, wherein T1 is in the range of Ac1 to Ac3+200 °C and wherein t1 is at most 12 minutes, b. transferring the heated blank to a hot-forming tool during a transport time t2 during which the temperature of the heated blank decreases from temperature T1 to a temperature T2, wherein T2 is above Ar1 and wherein the transport time t2 is at most 12 seconds, c. forming the blank in the hot-forming tool into an article and quenching it in the hot-forming tool from a temperature T2 to a temperature T3 at a cooling velocity V2 of 25 °C/s or more, d. isothermal holding the article at a temperature T4 for a time period t4, e. wherein temperature T3 and/or temperature T4 is between Ms and Mf and wherein t4 is more than 10 seconds and less than 10 minutes, f. cooling the article from temperature T4 to room temperature at a cooling velocity V4.20 The invention also

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[Continued on next page]

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relates to a hot-formed article obtained by the method.

METHOD FOR MANUFACTURING A HOT-FORMED ARTICLE, AND OBTAINED ARTICLE

[001] The invention relates to a method for hot forming a steel blank into an article having enhanced mechanical properties, such as an automotive part with improved ductility, bendability and impact toughness, and to a hot formed article obtained by said method.

[002] Recent progress in developing advanced high strength steels (AHSS) and ultra high strength steels (UHSS) enables automotive manufacturers to increase crashworthiness of automotive body parts and to reduce the weight through down gauging. However, cold formed AHSS and UHSS are still limited by formability, while cold and hot formed AHSS and UHSS are still limited by ductility and impact toughness.

[003] In attempts to solve the formability problem, hot forming (also known as hot stamping, hot-forming, press-hardening and die-quenching) has been developed. The basics of the hot forming technique and steel compositions adapted to be used were for the first time described in GB1490535.

[004] A typical steel used for the hot press forming is based on a composition system of 22MnB5, i.e. 0.22% of C, 1.2% of Mn, maximum 50 ppm of B, specified in EN10083. Hot press forming of 22MnB5 steel can produce complex parts such as bumpers and pillars with ultrahigh strength, minimum springback, and reduced sheet thickness. The tensile strength of boron steels is up to 1600 MPa, which is far above that of the highest-strength conventional cold stamping steels. However the ductility of total elongation is less than 6%.

[005] In a typical hot forming process using a 22MnB5 boron steel composition the blank is furnace-heated and austenitized at 900-950 °C, transferred from furnace to forming tool, and stamped into the desired part geometry. The blank has an ultimate tensile strength R_m<200 MPa and a total elongation A>50%. The formed blank is finally die-quenched to 100-200 °C with a mean cooling rate of >30 °C/s and a homogenous martensitic microstructure is obtained, while it is constrained in the forming tool. The final martensitic part typically exhibits a proof strength $Rp_{0.2}$>1100 MPa, an ultimate tensile strength R_m>1500 MPa and a total elongation A<8%. Hot stamped boron steel parts typically include anti-intrusive structural body parts such as roof pillar-, door beam- and bumper beam-reinforcements that constitute the 'safety-cell' of a car. The relatively soft and ductile high-temperature austenitic microstructure during forming permits down-

gauging and lightweighting while not compromising forming limits and moreover, permits part-consolidation and in turn, increased structural strength and increased process efficiency compared to cold forming as joining/welding is reduced. Forming above the ferrite recrystallization temperature, the martensitic transformation, which releases forming stresses and geometric constraint on the part during quenching, eliminates springback giving rise to geometric accuracy. The ultra high strength martensitic microstructure resulting in the final part permits down-gauging (lightweighting) simultaneously while improving anti-intrusive crashworthiness compared to the use of cold formed parts. The supremacy of boron steel in hot stamping applications owes to the (quench) hardenability (owing to the boron addition) and in turn ultra high strength martensitic microstructure that can be obtained from the relatively lean chemical composition. However, while hot stamped martensitic boron steel provides excellent mechanical properties for anti-intrusive crashworthiness, the limited ductility, and in turn limited toughness give rise to very poor impact-energy absorptive crashworthiness.

[006] EP1939308 A1 proposed a modification of the standard hot-forming method, wherein a complete martensitic transformation is avoided during hot-forming. A steel blank was heated up to its intercritical temperature between Ac1 and Ac3 and then hot-formed to a temperature below Ms so that a dual-phase microstructure consisting of martensite and proeutectoid ferrite is obtained. The hot-formed article obtained by said method showed improved elongation and tensile strength. However, it is well known that dual phase steels are sensitive to damage upon forming due to the large hardness difference between ferrite and martensite. The damage tolerance and formability of said hot-formed article is relatively poor due to the microstructural inhomogeneities and microcracks may occur during forming. As a result, the energy absorption capability of structural components in a car body is also limited.

[007] Therefore, hot-stamped boron steel and the advantages of the hot stamping process cannot be exploited with impact-energy absorptive structural body parts, such as fender and longitudinal beams that constitute ‘crumple zones’. Such parts are typically cold formed from ferritic or multiphase steels, such as Transformation Induced Plasticity (TRIP) steels.

[008] In order to meet the requirements of the automotive industry for lighter yet safer vehicles, there is an ongoing demand for steel articles having improved mechanical properties, such as improved tensile strength, ductility and impact toughness for impact-energy absorptive crashworthiness, while exhibiting excellent formability to enable down-gauging and moreover, while exhibiting excellent

dimensional accuracy (minimal or no springback).

[009] In the literature it has been proposed to use a Quenching-Partitioning-Tempering (Q-P-T) heat treatment, which could improve the mechanical performance of a quenched steel by partitioning and tempering. The proposed heat treatment comprises the steps of: a) heating a steel blank above the austenization temperature; b) quenching: controlling the quenching temperature to be between the Ms and Mf temperature of the steel to partially transform austenite into martensite; c) partitioning: raising the temperature slightly above the Ms temperature and holding it for a short time, whereby a thin layer of austenite with high content of carbon is formed around the martensite lath by repartitioning the carbon between martensite and austenite; d) tempering: tempering the steel at a temperature to induce precipitation hardening in martensite; and e) cooling: cooling down the steel from the tempering temperature at room temperature to transform part of retained austenite into martensite, while remain a thin layer of retained austenite with high content of carbon around the martensite lath generated previously (in step b) to attain the high toughness of the steel. After the Q-P-T heat treatment, the tensile strength of the medium carbon steels containing Si and Nb reaches 2000 MPa, and the total elongation reaches 11%. Therefore, the Q-P-T process has tremendous promising application in the industry.

[0010] It is therefore an object of the present invention to provide an improved method for hot-forming a steel blank into an article, as well as a steel composition suitable for use in said method, wherein the article has excellent mechanical properties, for anti-intrusive crashworthiness, enhanced ductility and in turn improved toughness, and thus improved impact-energy absorptive crashworthiness compared to conventional hot-formed boron steels and cold formed multiphase steels.

[0011] It is a further object of the invention to provide an improved method for hot-forming a steel blank into an article by integrating to the hot-forming process a Quenching-Partitioning-Temping (Q-P-T) heat treatment.

[0012] It is a further object of the invention to provide an improved method for hot-forming a steel blank into an article, wherein the article has high strength, high ductility and high bendability.

[0013] It is a further object of the invention to provide an improved method for hot-forming a steel blank into an article for impact-energy absorptive structural body parts that exhibits minimum or no springback and thus improved dimensional accuracy compared to conventional cold formed multiphase steels.

[0014] It is a further object of the invention to provide an improved method for hot-forming a steel blank into an article having good coatability.

[0015] It is a further object of the invention to provide an improved method for hot-forming a steel blank into an article enabling down-gauging and lightweighting simultaneously while improving impact-energy absorptive crashworthiness.

[0016] It is a further object of the invention to provide a hot-formed article with complex phase structure.

[0017] It is a further object of the invention to provide a method for hot-forming a steel blank into an article, wherein the article has higher total elongation (TE) and/or bending angle (BA) compared to conventional cold formed steels.

[0018] One or more of the above-mentioned objectives have been achieved by the present invention, which provides a method for hot-forming a steel blank into an article comprising the steps of:

a. heating a steel blank to a temperature T1 and holding the heated blank at T1 during a time period t1, wherein T1 is in the range of Ac1 to Ac3+200 °C and wherein t1 is at most 12 minutes,

b. transferring the heated blank to a hot-forming tool during a transport time t2 during which the temperature of the heated blank decreases from temperature T1 to a temperature T2, wherein T2 is above Ar1 and wherein the transport time t2 is at most 12 seconds,

c. forming the blank in the hot-forming tool into an article and quenching it in the hot-forming tool from a temperature T2 to a temperature T3 at a cooling velocity V2 of 25 °C/s or more,

d. isothermal holding the article at a temperature T4 for a time period t4,

e. wherein temperature T3 and/or temperature T4 is between Ms and Mf and wherein t4 is more than 10 seconds and less than 10 minutes,

f. cooling the article from temperature T4 to room temperature at a cooling velocity V4.

[0019] The inventors have found that through forming the heated blank into an article as described above, complex shaped articles with enhanced mechanical properties can be obtained. In particular the articles exhibit excellent impact-energy absorptive crashworthiness and in turn, down-gauging and lightweighting opportunities based on impact-energy absorptive crashworthiness compared to the use of conventional hot-formed boron steels and cold-formed multiphase steels.

[0020] In the common hot forming process, the steel blank is simply formed into the desired geometry at and then die-quenched to near-ambient temperature in which a complete transformation to martensite takes place. Thus, the final part exhibits a fully or almost fully martensitic microstructure.

[0021] The inventors have surprisingly found that by interrupting the die-quench and integrating a Q-P-T heat treatment in the hot-forming cycle, hot formed steel articles having a distinctive microstructure and thus improved mechanical properties can be obtained.

[0022] In particular the inventors have found that by interrupting the quench temperature of the hot-forming process at a temperature T3 and/or a temperature T4 between Ms and Mf and applying a Q-P-T heat treatment, it is possible to control the phases formed, as well as the amount of each phase formed, thus the microstructure, and consequently the mechanical properties of the article. Said article shows improved mechanical properties, such as enhanced tensile strength, ductility and impact toughness for impact-energy absorptive crashworthiness, while exhibiting excellent formability to enable down-gauging and moreover exhibiting excellent dimensional accuracy (minimal or no springback).

[0023] In step (c) a heated blank is formed in a forming tool into the desired part geometry having a partially or a fully homogenous austenitic microstructure and simultaneously quenched to a(n) (interrupt) temperature T3, and preferably at a cooling velocity V2 of 25 °C/s or more. The inventors found that when T3 is too high and above Bs, and/or the cooling rate is too low, pearlite may form. When V2 is less than 25°C/s, there is also a risk of carbide formation resulting in degradation of the mechanical properties of the final article. Better results have been achieved when the cooling rate V2 is at least 50 °C/s, preferably at least 100 °C/s. Advantageously the cooling rate V2 is at least 150 °C/s for best results.

[0024] According to step (e) the article is brought to a temperature T4 and isothermally held at that temperature T4 for a time t4. Isothermal holding time t4 is the time required for austempering, partitioning or tempering and is in the range of 10 seconds to 10 minutes. When t4 is more than 10 minutes then no further improvement of the article is achieved. If t4 is less than 10 seconds then there is not enough time for the effect to be achieved.

[0025] According to a preferred embodiment T3 is between Ms and Mf and T4 is between Bs and Ms. For the process of this embodiment the article must be heated up from temperature T3, which is lower than Ms, to temperature T4, which is higher than Ms. At the temperature T3, some martensitic transformation will take place. The amount of the martensite formed is mainly controlled by the temperature T3: the lower T3, the higher the fraction of martensite. Since T4 is higher than T3, the untransformed austenite will transform to bainite and retained austenite at T4 and during following cooling. The martensite will be tempered to some degree during the isothermal holding at T4.

[0026] According to a further preferred embodiment T3 is between Bs and Ms and T4 is between Ms and Mf. In the method according to this embodiment, austenite will first partially transform into bainite at temperature T3. The untransformed austenite will transform to martensite and retained austenite during isothermal holding at T4 and the following cooling.

[0027] In another preferred embodiment both T3 and T4 are between Ms and Mf, and preferably T3 and T4 are the same. Some martensite will form at the beginning; as the isothermal holding time increases, element partitioning between martensite and untransformed austenite may occur, the Ms point of the untransformed martensite will be decreased and some untransformed austenite may transform to bainite. At the same time, the transformed martensite might be tempered to some degree.

[0028] Preferably, the article that is formed is held at temperature T3 during a holding time t3 of 1 to 180 seconds. The length of the holding time t3 determines the amount of the microstructural elements that are first formed at temperature T3. Which microstructural elements are first formed depends on temperature T3.

[0029] When T3 is between Ms and Mf and T4 is between Bs and Ms, usually the article is heated from temperature T3 to temperature T4 at a velocity V3 of at least 15 °C/s, preferably at least 20 °C/s, more preferably at least 30 °C/s. The heating velocity V3 depends on the temperature difference between T3 and T4, and on the sheet thickness.

[0030] When T3 is between Bs and Ms and T4 is between Ms and Mf, usually the article is cooled from temperature T3 to temperature T4 at a velocity t3 of at most 15 °C/s, preferably at most 10 °C/s, more preferably at most 8 °C/s. The cooling velocity V4 depends on the temperature difference between T3 and T4, and on the sheet thickness.

[0031] In a further preferred embodiment the article is cooled from temperature T4 to room temperature at a cooling velocity V4, in the range of 0.1 - 20 °C/s, preferably in the range of 1 - 15 °C/s, more preferably in the range of 2 - 10 °C/s. This cooling can be performed by natural cooling in air or by using an air blower, for instance.

[0032] Preferably, T1 is in the range of Ac1 to Ac3+150, preferably Ac1 to Ac3+100, more preferably in the range of Ac3-50 to Ac3+50, and wherein t1 is preferably at most 12 minutes, more preferably t1 is in the range of 2-8 min, and wherein the steel blank is heated with a heating velocity V1 in the range of 10 - 25 °C/s. Temperature T1 determines how much ferrite is transformed into austenite in the steel blank, which also depends on the holding time t1. A heating velocity V1 above 25 °C/s can be detrimental to the properties of the blank.

[0033] Optionally after step (e) the article undergoes fine forming.

[0034] In the method according to the present invention a steel strip or sheet is provided as an intermediate for the subsequent steps. The steel strip or sheet can be obtained by standard casting processes. In a preferred embodiment the steel strip or sheet is cold-rolled.

[0035] The steel strip or sheet is cut to a steel blank and then heated to a temperature T1 for a time period t1. A preformed steel blank may also be used. The preformed blank may be partially or entirely formed into the desired geometry, preferably at ambient temperature.

[0036] The heating apparatus may be an electric or gas powered furnace, electrical resistance heating device, infra-red induction heating device or any other heating device.

[0037] In a preferred embodiment T1 is in the range of Ac1 to Ac3, the blank is austenitized at an intercritical temperature. The steel has at said temperature range a ferritic austenitic microstructure. Under this conditions preferably a small amount of the ferrite is retained, wherein the ferrite fraction is preferably less than 20 vol.%. In this case press hardening takes place wherein the structure of the steel part is a two-phase mixture of ferrite and austenite. After subsequent press hardening and Q-P-T heat treatment, a mixed structure of ferrite, bainite or martensite, tempered martensite and a portion of residual austenite is produced in the component.

[0038] In a further preferred embodiment T1 is above the chemistry specific Ac3 temperature to produce a fully or almost fully homogenous austenitic microstructure with uniform distribution of carbon. When the microstructure is a homogenous austenitic microstructure the formability is enhanced.

[0039] The inventors have further found that austenization time t1 may be chosen in combination with the temperature T1 and the blank thickness in order to control austenitic grain growth and associated quench hardenability of said steel. The degree of quench hardenability will then influence the microstructural evolution during cooling. Therefore, t1 is at most 12 min. Preferably t1 is in the range of 2-8 minutes, more preferably in the range of 2-6 minutes in view of process and energy efficiency.

[0040] The steel blank is transferred from the heating apparatus to a forming tool in a time period t2 (step b). Time t2 is the time needed to transport the heated blank from the heating apparatus to the press forming tool and till the hot-forming apparatus is closed. During the transfer the blank may cool from temperature T1 to temperature T2 by the act of natural air-cooling and/or any other available cooling method.

[0041] The heated blank may be transferred from the heating apparatus to the forming tool by an automated robotic system or any other transfer method.

[0042] Time t2 may also be chosen in combination with T1, t1 and T2 in order to control the microstructural evolution of steel at the commencement of forming and quenching. Time period t2 is preferably chosen such to ensure that the steel blank when placed in the hot-forming tool has a temperature T2 above the temperature Ar1 of the steel to exhibit an austenitic-ferritic microstructure and prevent the formation of pearlite. On the other hand shorter transport times are beneficial in view of corrosion, process efficiency and hardenability. The inventors have further found that when t2 is equal or less than 10 s good results have been also achieved. Preferably t2 is equal or less than 8s, more preferably equal or less than 6s.

[0043] It is a further object of the present invention to provide a steel composition suitable for any one of the methods described herein.

[0044] According to the present invention the steel blank comprises, in weight % (wt%) following elements:

C: 0.10-0.50, preferably 0.15-0.40, more preferably 0.20-0.35,
Mn: 0.50-4.00, preferably 1.00-3.00 more preferably 1.00-2.50,
Si: $\leq$2.0; preferably 0.1-2.0, more preferably 0.1-1.6,
Al: $\leq$2.0, preferably $\leq$1.0, more preferably $\leq$ 0.5,
Cr: $\leq$1.5, preferably $\leq$ 1.2, more preferably 0.001-1.1,
Ti: $\leq$0.10, preferably $\leq$0.05, more preferably $\leq$0.04,
B: $\leq$0.008, preferably $\leq$0.005,
Nb: $\leq$0.10, preferably $\leq$0.05, more preferably 0.001-0.05,

and optionally one or more of the elements selected from

V: ≤0.2, preferably ≤0.1

Ca: ≤0.003, preferably 0.0003-0.003,

N: ≤0.005, preferably ≤0.003,

P: ≤0.015,

S: ≤ 0.03, preferably <0.01.

Mo:≤0.5, preferably ≤0.05,

Cu: ≤1.0,

Ni: ≤1.0,

the remainder being Fe and unavoidable impurities.

[0045] The reason for the amounts of the elements is as follows (in wt%).

[0046] C: 0.10-0.50. C is an essential element for securing a high strength. C is added in an amount of 0.10% or more to form required complex phase microstructures and achieve high strength and high ductility. More particularly, together with the intercritical austenization temperature, the C content determines the volume of ferrite and the carbon content of the remaining austenite, which controls the Bs and Ms points and the bainite formation kinetics. When the C content exceeds 0.50, there is a great possibility that the toughness and weldability of the steel sheet will deteriorate. C amount is preferably present in the range of 0.15-0.40, more preferably in the range of 0.20-0.35.

[0047] Mn: 0.50-4.00 The functions of the Mn is to stabilize the austenite and to obtain the desired multiphase microstructure. The manganese content is at least 0.50 in order to provide adequate substitutional solid solution strengthening, adequate quench hardenability and adequate stabilisation of austenite at ambient temperature, while minimising segregation of Mn during casting and while maintaining sufficiently low carbon equivalent for automotive resistance spot-welding techniques. If the Mn content is less than 0.50 is difficult to attain an intended high strength of the steel by heat treating the steel in a ferrite-austenite two-phase region. When the Mn content exceeds 4%, there is the dangers that the steel sheet suffers from poor weldability and hot rolling characteristics. Besides, Mn is an element that is useful in lowering the Ac3 temperature. A higher Mn content is advantageous in lowering the temperature necessary for hot press forming. Preferably, the Mn content is limited to the range of 1.0% to 3.0%. Advantageously, manganese is in the range of 1.00-2.50.

[0048] Si: ≤ 2.0. Si is an element effective for reinforcing a solid solution, and is useful for suppressing production of carbide due to decomposition of retained austenite. A certain amount of Si suppresses the precipitation of brittle cementite during bainite formation, and hence leads to an improvement in formability and toughness. Si is further known to widen the intercritical temperature range of a steel. However, Si is also known that in high amount the coatability deteriorates due to the formation of oxides adherent to the steel substrate. Therefore, the Si amount is equal or less than 2.0, preferably in the range of 0.1-2.0. In view of coatability, when articles having good coatability/galvanizability are desired, the Si content is preferably in the range of 0.1-1.0. When steel articles having higher ductility are aimed, then the Si content is preferably in the range of 1.0-2.0.

[0049] Al $\leq$ 2.0: Al limited to a maximum of 2.0 in order to preserve weldability and minimise 'nozzle blockage' during steelmaking and casting. Al is an element useful for suppressing production of carbide due to decomposition of, particularly, retained austenite. Partial replacement of Si by same amount of Al has been shown to effectively retard carbide formation without a detrimental effect on hot-dip coatability in steels. However, a high concentration of Al leads to higher possibility of the polygonal ferrite to be created, which is less effective than fine plate ferrite on strength. Preferably Al is limited to a maximum of 1.0, more preferably Al is at most 0.5.

[0050] Si and Al in sufficient amount can completely resist formation of carbide. A carbide free bainite (i.e. bainitic ferrite) that forms at lower temperature part of the thermal cycle exhibits higher elongation. With lower Si + Al (Si + Al < 5 x C), traditional bainite (consisting of bainitic ferrite + cementite) will form. Therefore, in the best composition, higher amount of Si can be replaced by optimum amount of Al that is known to improve coatability.

[0051] P $\leq$ 0.015: P is known to widen the intercritical temperature range of a steel. P is also an element useful for maintaining desired retained austenite. However, P may deteriorate the workability of the steel when it is added in an excess amount. Therefore, P cannot be added deliberately beyond its usual permissible limit in steel <0.015 wt.%.

[0052] S $\leq$ 0.03. Sulphur needs to be minimised for minimisation of harmful non-metallic inclusions. S forms a sulfide based inclusions such as MnS, which initiates crack, and deteriorates processability. Therefore, it is desirable to reduce the S amount as much as possible. Therefore the sulphur content is limited to a maximum of 0.03, preferably to a maximum of 0.01.

[0053] Mo $\leq$ 0.5 and Cr $\leq$ 1.5: Mo and Cr are elements which improve the hardenability of the steel and facilitate the formation of bainite ferrite, and at the same time, are elements having similar effectiveness useful for stabilizing retained austenite. Therefore, Mo and Cr are very effective for the process control. Preferably Mo and Cr are each present in an amount of 0.001% or higher. However, when each of them is added excessively, the effect is saturated and the process is not economical. Therefore, the amounts of Mo is limited to a maximum of 0.5, preferably at most 0.05. Cr is limited to a maximum of 1.5, preferably 1.2. Advantageous Cr is in the range of 0.001-1.1

[0054] Ti$\leq$0.1; Nb$\leq$0.1; V$\leq$0.2: Ti, Nb and V have the effect of forming strengthening precipitates and refining microstructure. The steel should have sufficient strength level. Due to the soft phases such as proeutectoid and bainitic ferrite, the strength of the final product can be lower than standard hot formed material. To compensate for this drop in strength, microalloying elements such as Nb, Ti and V might be added individually or in combination. Said elements increase the strength by means of grain refinement and precipitation hardening. Grain refinement results in a more homogeneous microstructure improving the hot-forming behaviour, in particular when high localized strains are being introduced. Therefore the amount of Ti and Nb is each limited to a maximum of 0.1, preferably to a maximum of 0.05. Advantageously Ti is at most 0.04 and/or Nb is in the range of 0.001-0.05. The amount of V is limited to a maximum of 0.2 %, preferably to a maximum of 0.10.

[0055] Ca$\leq$0.003%: Ca is an element effective for controlling a form of sulfide in the steel, and improving processability. However, It is recommended that Ca is contained at 0.0003% or more. However, when it is added excessively, the effect is saturated. Therefore, it is better to suppress an amount thereof to 0.003% or less.

[0056] B$\leq$0.008. B is an important element for increasing the hardenability of 22MnB type steel sheets and for further increasing the effect of stably guaranteeing strength after hardening. However, B is an optional element for the relatively high carbon contented steel. When B is to be used then the B amount is preferably limited to a maximum of 0.008, preferably at most 0.005. When B is added to steel having relative low carbon levels, it is preferred that the B amount is in the range of 0.0005-0.0025 %.

[0057] In a preferred embodiment the steel microstructural composition is a multiphase steel, preferably a complex phase (CP) like steel that exhibits the capacity for stress/strain induced transformation effect. More particularly the steel is an advanced high strength steel product suitable for hot press forming as a boron steel alternative for automotive applications.

[0058] The inventors have surprisingly found that applying the present method to a CP like steel composition results in hot-formed articles exhibiting homogeneous mechanical properties. The relative fraction of the existing phases in the microstructures depends essentially on the initial chemical composition of the steel and on the method conditions under which the various step are performed. For a given steel composition, by careful controlling the present hot-forming process as described above, a CP microstructure comprising bainite, martensite, tempered martensite and/or retained austenite can be obtained, wherein the phases are homogeneously distributed in each of the regions of the part.

[0059] In addition to the above, and compared to the traditional hot stamped boron steel, the articles obtained by the present invention show vastly improved mechanical properties comparable to those of the traditional CP steel prior to cold forming, and thus impact-energy absorptive crashworthiness can be achieved.

[0060] The present invention provides an improved method of introducing during hot-forming operation the desired bainitic gradient into the steel microstructure while with the standard hot-forming methods this is not possible. Further, the standard hot-forming processes can not provide sufficient amount of tempered martensite and retained austenite in the steel.

[0061] In order to be able to exploit the advantageous characteristics obtained with the invention in a particularly reliable way, the bainite and tempered martensite portions in the structure of the formed steel part at the end of the Q-P-T heat treatment should be in total at least 80%, while the amount of the other phases should be less than 20%.

[0062] In a more preferred embodiment the final microstructure consist of (vol.%) (sum should be add 100).

- at least 80 vol.% bainite and tempered martensite, wherein the tempered martensite is less than 50 vol.%, preferably equal or less than 40 vol.%, more preferably equal or less than 30 vol.%, and
- at most 20 vol.% ferrite and/or martensite, and/or retained austenite.

[0063] The metastable retained austenite fraction ensures the balanced combination of strength and ductility properties. Retained austenite enhances ductility partly through the stress / strain induced transformation effect, which manifests itself in an observed increase in uniform elongation and total elongation as the work hardening exponent increases to higher plastic strains. Above 20 vol.% the desired level of ductility and/or uniform elongation according to the present invention will not be achieved.

[0064] Part or the totality of the process according to the present invention may be conducted in a controlled inert atmosphere of hydrogen, nitrogen, argon or any other inert gas in order to prevent oxidation and/or decarburisation of said steel.

[0065] The inventors have further found that the hot-formed article obtained by the present invention has ultimate tensile strength (UTS) of at least 1000 MPa, preferably at least 1100 MPa and/or yield strength of at least 600 MPa, preferably at least 700 MPa, and/or a total elongation (TE) of at least 6% and/or a bending angle of at least 45 °, preferably 50 °C, the obtained product exhibits improved impact-energy absorptive crashworthiness.

[0066] According to a preferred embodiment the steel strip, sheet, blank, preformed blank, or article is provided with a coating. The addition of a coating to the steel strip, sheet, blank or the preformed blank may be performed prior to the hot-forming process or after the hot-forming process and has the purpose of minimising oxidation of the steel when exposed to an oxidising atmosphere at high temperature and/or providing cathodic corrosion protection of the final hot formed part.

[0067] In a preferred embodiment the steel strip, sheet, blank, preformed blank, or article is coated with a zinc based coating, aluminium-silicon based coating or an organic based coating.

[0068] The zinc based coating is a galvanized or galvannealed coating. Although the coating can be applied in various ways, hot dip galvanising is preferred using a standard GI coating bath. Other Zn coatings may also be applied. An example comprises a Zn alloy coating according to WO 2008102009, in particular a zinc alloy coating layer consisting of 0.3-4.0 wt% Mg and 0.05-6.0 wt% Al and optionally at most 0.2 wt% of one or more additional elements along with unavoidable impurities and the remainder being zinc. An additional element typically added in a small amount of less than 0.2 wt%, could be selected from the group comprising Pb or Sb, Ti, Ca, Mn, Sn, La, Ce, Cr, Ni, Zr or Bi. Pb, Sn, Bi and Sb are usually added to form spangles. Preferably, the total amount of additional elements in the zinc alloy is at most 0.2%. These small amounts of an additional element do not alter the properties of the coating nor the bath to any significant extent for the usual applications. Preferably, when one or more additional elements are present in the zinc alloy coating, each is present in an amount $\leq$0.02 wt%, preferably each is present in an amount $\leq$0.01 wt%. Additional elements are usually only added to prevent dross forming in the bath with molten zinc alloy for the hot dip galvanising, or to form spangles in the coating layer.

[0069] The articles according to the present invention exhibit good adhesion to a coating layer, have good surface appearance and superior corrosion resistance after coating.

[0070] It is a further object of the present invention to provide with an article obtained by any one of the methods described herein.

[0071] Figure 1 shows a schematic representation of a first embodiment of the method according to the invention.

[0072] Figure 2 shows a schematic representation of a second embodiment of the method according to the invention.

[0073] Figure 2 shows a schematic representation of a third embodiment of the method according to the invention.

[0074] In the figures the horizontal axis represents the time t, and the vertical axis represents the temperature T. The hot forming of the blank into the article in the hot forming press is indicated by HF. The time t and temperature T are indicated diagrammatically in the Figures, and so are the cooling and heating velocities V. No values can be derived from the Figures.

[0075] A steel blank is heated up to the austenitizing temperature T1 above Ac_1 at a heating rate of 15 °C/s and held at aT1 for a time period t1. Then the heated blank is transferred from the furnace to the hot forming press, during which cooling of the blank to temperature T2 by air occurs to some extend. Care is taken that the temperature T2 does not decrease below the Ar1 temperature before the blank is placed in the hot-forming press. The blank is then hot-formed into an article and cooled down to temperature T3 at a cooling rate of >25 °C/s and the cooling is interrupted and the article is held at T3 for a time period t3. Thereafter, the three embodiments follow different routes. Finally, the formed article is cooled down to room temperature at a cooling rate V4.

[0076] The values for the temperatures T3, T4 and cooling or heating velocities V3 and V4, and the holding time t3 and t4 depend on the different embodiments as shown in the Figures 1 - 3.

[0077] The different temperatures are explained below.

[0078] Ac1:Temperature at which, during heating, austenite starts to form.

[0079] Ac3: Temperature at which, during heating, transformation of the ferrite into austenite ends.

[0080] Ar1: The temperature at which transformation of austenite to ferrite is completed during cooling.

[0081] Ar3: The temperature at which austenite begins to transform to ferrite during cooling.

[0082] Bs: Temperature at which, during cooling, transformation of the austenite into Bainite starts.

[0083] Ms: Temperature at which, during cooling, transformation of the austenite into martensite starts.

[0084] Mf: Temperature at which, during cooling, transformation of the austenite into martensite ends.

[0085] Critical phase transformation temperatures are determined by dilatometer experiments.

[0086] The invention will be elucidated by means of the following, non-limiting examples making reference to the accompanying figures. Table 1 shows the steel composition used in a method according to the present invention. The tables 2, 3 and 4 give the process parameters and mechanical properties for the different steel types of Table 1, and for the process types of the three embodiments. The results are discussed below.

Table 1. Steel compositions (wt.%).

Steel	C	Si	Mn	Cr	Al	P	S	Ti	Nb	B	A_{c3} (°C)	M_s (°C)
B	0.31	1.47	1.66	0.05	0.02	0.006	0.004	0.003	<0.005	<0.0001	865	330
C	0.29	1.55	2.0	0.005	0.008	0.005	0.005	0.004	<0.005	<0.0001	830	310
D	0.26	1.54	1.5	1.05	0.009	0.005	0.005	0.004	<0.005	<0.0001	850	340
E	0.29	0.29	1.23	0.48	0.03	0.012	0.005	0.025	0.031	0.0031	831	360
F	0.26	1.48	1.77	0.003	0.015	0.010	0.008	0.007	<0.005	0.0003	855	340
G	0.25	0.21	2.4	0.003	0.018	0.012	0.009	0.005	<0.005	0.0019	800	330
H	0.22	1.0	2.1	0.004	0.03	0.005	0.004	0.004	<0.005	<0.0001	845	375
J	0.31	1.53	1.98	1.04	0.011	0.01	0.01	0.027	<0.005	<0.0001	805	285

Table 2. Process parameters and mechanical properties of process type 1

Steel	T1	t1	T2	t2	T3	t3	T4	t4	YS	UTS	TE	BA	Note*
	°C	min	°C	s	°C	s	°C	s	MPa	MPa	%	°	
B1	900	6			25	0	25	0	1147	1881	4.5	35	Ref.
B2	900	6	780	6	260	5	350	60	907	1371	7.2	63	Inv.
B3	900	6	780	6	200	5	350	60	1046	1337	7.7	68	Inv.
B4	900	6	780	6	220	5	350	60	736	1314	9.2	70	Inv.
B5	900	6	780	6	220	5	450	60	574	1058	22	79	Inv.
B6	820	6	780	5	260	5	380	600	856	1319	15	75	Inv.
C1	880	6			25	0	25	0	1283	1941	6.2	41	Ref.
C2	880	6	760	6	300	5	400	30	1252	1782	7.8	55	Inv.
C3	880	6	760	6	300	5	400	60	1319	1718	9.1	55	Inv.
C4	880	6	760	6	300	5	400	120	1184	1511	9.8	52	Inv.
C5	880	6	760	6	300	5	400	180	1412	1606	6.6	62	Inv.
D1	880	6			25	0	25	0	1269	1865	5.7	47	Ref.
D2	880	6	760	6	300	5	400	30	1184	1714	8.7	53	Inv.
D3	880	6	760	6	300	5	400	60	1116	1564	7.6	50	Inv.
D4	880	6	760	6	300	5	400	120	1341	1596	6.2	57	Inv.
D5	880	6	760	6	300	5	400	180	1362	1590	6.9	55	Inv.
E1	900	2			25	0	25	0	1101	1671	5.8	60	Ref.
E2	810	2	750	5	340	0	400	180	509	1166	11.9	65	Inv.

*V2 = -40°C/s; V3 = 20°C/s; V4 = - 5°C/s.

Table 3. Process parameters and mechanical properties of process type 2

Steel	T1	t1	T2	t2	T3	t3	T4	t4	YS	UTS	TE	BA	Note*
	°C	min	°C	s	°C	s	°C	s	MPa	MPa	%	°	
D6	880	6	760	5	350	30	320	120	1210	1590	7.1	50	Inv.
D7	880	6	760	5	350	60	320	120	1132	1523	8.5	63	Inv.
D8	880	6	760	5	350	120	320	120	1076	1456	9.2	66	Inv.
D9	880	6	760	5	350	180	320	120	1053	1415	10.5	70	Inv.

*V2 = -40°C/s; V3 =- 3°C/s; V4 =- 5°C/s.

Table 4: Process parameters and mechanical properties of process type 3

Steel	T1	t1	T2	t2	T3=T4	t3+t4	YS	UTS	TE	BA	Note*
	°C	min	°C	s	°C	s	MPa	MPa	%	°	
F1	900	2			25	0	1115	1661	6.5	43	Ref.
F2	900	2	860	5	310	20	1074	1619	9.0	52	Inv.
F3	900	2	860	5	310	30	950	1515	9.3	52	Inv.
F4	900	2	860	5	310	60	968	1533	11.2	66	Inv.
F5	900	2	860	5	310	120	984	1482	8.0	79	Inv.
F6	900	2	860	5	270	20	1112	1651	8.9	45	Inv.
F7	900	2	860	5	270	30	863	1455	8.9	54	Inv.
F8	900	2	860	5	270	60	983	1547	9.1	56	Inv.
F9	900	2	860	5	270	120	896	1438	8.0	62	Inv.
G1	850	2			25	0	1129	1639	6.2	62	Ref.
G2	850	2	730	5	300	20	1076	1577	7.6	64	Inv.
G3	850	2	730	5	300	30	1063	1527	6.3	72	Inv.
G4	850	2	730	5	300	60	1032	1493	7.1	80	Inv.
G5	850	2	730	5	300	120	964	1433	7.9	88	Inv.
G6	850	2	730	5	260	20	1072	1589	7.7	61	Inv.
G7	850	2	730	5	260	30	1088	1579	7.2	68	Inv.
G8	850	2	730	5	260	60	1051	1543	7.2	76	Inv.
G9	850	2	730	5	260	120	992	1527	7.8	79	Inv.
H1	900	2			25	0	1050	1450	6.0	41	Ref.
H2	900	2	860	5	300	40	923	1489	8.2	52	Inv.
H3	900	2	860	5	300	60	962	1499	8.2	50	Inv.
H4	900	2	860	5	340	20	1028	1502	8.8	56	Inv.
H5	900	2	860	5	340	40	951	1437	8.7	52	Inv.
H6	900	2	860	5	340	60	897	1434	8.8	56	Inv.
I1	900	2			25	0	980	1402	5.9	43	Ref.
I2	900	2	860	5	300	20	865	1376	6.5	88	Inv.
I3	900	2	860	5	300	40	755	1371	8.4	92	Inv.
I4	900	2	860	5	300	60	1033	1360	7.0	79	Inv.

*V2 = -50°C/s; V4 = -5°C/s

[0084] Examples with steel compositions B, C and D

Steel blanks with dimensions of 200 mm × 110 mm × 1.5 mm have been prepared from a cold-rolled steel sheet having the composition B or C as given in Table 1. The Ac3 and Ms temperatures were determined using dilatation tests.

The blanks were first heated at 880 °C (T1) in a box furnace for 6 min and then transported to a hot-forming apparatus. The hot-forming was performed in laboratory scale by Schuler SMG company, Germany (hereafter SMG press). The SMG press tools were preheated to a temperature of 450 °C or 300 °C (T3). The blanks were transferred to the SMG press in 10 s and press-quenched to T3 temperature into an article. The article was transferred to a muffle furnace preheated at a temperature of 350°C or 400 °C (T4) and austempering or partitioning and/or tempering heat treatment was applied (Q-P-T treatment).

The experimental results with respect to the yield strength (YS), ultimate tensile strength (UTS), uniform elongation (UL) total elongation (TL) and banding angle (BA), are given in Table 2 and Table 3. The tensile properties were measured in the samples with the stress direction being parallel to the rolling direction. The 3-point “guided bending tests” were conducted on samples with dimensions 40 mm x 3025 mm. The length direction of the samples was parallel to the rolling direction of steel sheets. Parallel bending tests where the bending axis is perpendicular to the rolling direction of the sheets were carried out. For this method, a former and two supporting cylinders were used in order to bend the steel sheets. The cylinders and the punch were mounted in a tensile testing machine. The load cell is used to measure the punch force and the displacement of the crosshead gives the punch displacement. The experiments were stopped at different bending angles and the bent surface of the specimen was inspected for identification of failure in order to determine the bending angle.

[0085] Examples with steel composition E

The present inventive method has been applied to a steel composition E, as shown in Table 2, similar to the known 22MnB5, but with a C content higher than from this of 22MnB5. The Ac1, Ac3, and Ms temperatures were determined using dilatation tests.

A cold-rolled steel sheet having the composition E and a thickness of 1.5 mm has been prepared and blanks with dimensions of 600 mm ×110 mm were cut. A thermal cycle according to the invention was applied to simulate the hot press forming process using a continuous annealing simulator (CASIM). The blanks were first heated to a variable soak temperature of 900 °C or 810 °C (T1) and held at said temperature for a soak time of 2 min (t1). The transfer of the heated blanks from the furnace to the press forming apparatus was simulated by cooling down slowly the blanks to 750 °C (T2) and at a cooling rate of 3 °C/s. The blanks are cooled down to a temperature T3 at a cooling rate of 40 °C/s (V2) and isothermal held for t3 and subsequently cooled down to room temperature at a cooling rate of 3.5°C/s (V4). In said experiments T3=T4. The process parameters, the tensile properties and the bending angle are given in Table 2.

[0086] Examples with steel compositions F, G, H, I and J

Steel compositions F, G, H, I and J according to table 1 have be used . Steel blanks with dimensions of 600 mm × 110 mm × 1.5 mm or 230 mm x 110 mm x 1.5 mm have been prepared from a cold-rolled steel sheets having the composition F, G and H, I, J respectively as given in Table 1.

The blanks of steel F and G were heat treated in a Continuous Annealing Simulator (CASIM), those of steels H, I and J in a Hot Dip Annealing Simulator (HDAS). Whatever be the apparatus used for heat treatments, it was ensured that the thermal cycles were simulated accurately.

The blanks of steels F and G were first heated to 900 °C and 850 °C (T1) respectively in CASIM and soaked for 2 min (t1). Then the blanks were cooled to 860 °C (for T1 = 900 °C) and 730 °C (for T1 = 850 °C) in 10 s to simulate the transfer of the blanks from reheating furnace to the hot press (T2). Then, either from 860 or from 730 °C, the blanks were cooled at a rate of 40 °C/s to an isothermal holding temperature below the Ms of these steels (here T3 = T4 and the two isothermal steps are combined into one step). Then, the blanks of steel F were isothermally held at 310 and 270 °C for time spans of 0, 20, 30, 60 and 120 s (t3 = t4) and then cooled to room temperature at a rate of 5 °C/s. On the other hand, the blanks of steels H and I were isothermally held at 300 and 260 °C for time durations of 0, 20, 30, 60 and 120 s (t3 = t4) before cooling to room temperature at a rate of 5 °C/s.

The blanks of steels H and I were heated to 900 °C (T1) in HDAS apparatus and soaked for 2 min (t1). Then the blanks were cooled to 860 °C (T2) in 10 s to simulate the transfer of the blanks from reheating furnace to the hot press, before cooling them at a rate of 50 °C/s to 300 or 340 °C (here also T3 = T4 and the two isothermal steps are combined into one step). These two temperatures are below Ms of steels H and I as evident from Table 1. Then, the blanks of steels H and I were isothermally held at either 300 or 340 °C for time spans of 0, 20, 40 and 60 s (t3 = t4) following cooling to room temperature at a rate of 5 °C/s.

For the blanks of steel J the following heat treatment procedures were followed in HDAS. The blanks were heated to 900 °C (T1) in HDAS apparatus and soaked for 5 min (t1). Then the blanks were cooled to 860 °C (T2) in 10 s to simulate the transfer of the blanks from reheating furnace to the hot press, before cooling them at a rate of 50 °C/s to 300, 325, 350, 375 and 400 °C (here also T3 = T4 and the two isothermal steps are combined into one step). These temperatures lie above the Ms of steel J as can be seen from Table 1. Then, the blanks were isothermally held at those temperatures for time spans of 0, 600, 1800 and 3600 s (t3 = t4) following cooling to room temperature at a rate of 5 °C/s.

It is to be mentioned that for the blanks of steels F, G, H and I the processes described above are basically one-step quenching and partitioning (Q&P) process since T3 = T4 < Ms. For steel J, it is austempering process (T3 = T4 > Ms) which was used for

bainitic transformation to take place. When t3 (= t4 as well) was 0 s, this specific blank basically represent the reference sample which experienced the thermal cycles of a standard hot forming, i.e. without application of the Q&P or austempering step.
The process parameters and mechanical properties of steels are given in Table 4.

[0087] The tensile properties and bendability of the steels are presented in Table 2 through 4 along with their heat treatment process parameters. According to thermal cycles applied, steels C, D, E have gone through two-step low temperature process combining bainitic and martensitic transformation, tempering and partitioning (Table 2). Steels F, G, H and I have undergone one-step heat treatment below Ms causing martensitic transformation and partitioning to take place (Table 3). In steel J, only bainitic transformation took place during the one-step austempering step (Table 4).
In the reference samples in Tables 2-4, predominantly martensitic microstructures formed as usual for standard hot forming process. The microstructure developments in the steels due to the modified process of this invention are described below.

0088] In steel C, in case of conditions C1 to C5, during first isothermal holding at T3, bainitic transformation took place and during the second holding at T4, again bainitic transformation took place enriching the remaining austenite in carbon and increasing the effective bainite content in the final microstructure. For conditions C6 to C9, during first holding (T3) a small amount of martensite formed as T3 was below the Ms of steel C. Then during second holding at T4, bainitic transformation took place in an accelerated manner as presence of small amount of martensite is known to accelerate bainitic transformation kinetics. During final cooling to room temperature, in all the conditions high amounts of retained austenite were obtained with some amounts of fresh martensite. For steel D, in conditions D6 to D9 similar phase transformations as in C6 to C9 took place except that more amount of martensite was formed at T3. Additionally, in conditions C6 to C9 and D6 to D9 tempering of the initially formed martensite and carbon portioning from this martensite to austenite would take place.
For steel D, in conditions D1 to D5 during first isothermal holding bainitic transformation took place at T3, and then at T4 some amount of martensite formed. At T4, tempering of this martensite and carbon portioning from martensite to austenite occurred. During final cooling to room temperature, some fresh martensite formed and some austenite remained untransformed. For steel E, in condition E2, the austenitizing

temperature T1 is in the intercritical range and one step austempering took place during isothermal holding (T3 = T4), with carbon enrichment in austenite. The final microstructure includes ferrite (15 vol.%), bainite/tempered martensite and retained austenite. The presence of ferrite increases the elongation but at expense of strength.
Certain amount of austenite transformed to martensite in steels F, G, H and I after quenching to the isothermal holding temperature (T3 = T4) since this temperature is below the Ms of the respective steels. The amount of this initial martensite varied with the temperature of quenching – a lower temperature in a particular steel would form a higher amount of initial martensite. The well-known Koistinen-Marburger formula can be used to estimate this initial martensite fraction. Then during the isothermal holding the martensite would temper, and at the same time carbon will partition from martensite to austenite. Carbon partitioning will be more for higher Si content in steel and vice versa. Then during final cooling to room temperature some fresh martensite will form depending on the carbon enrichment in austenite, and some amount of austenite will remain as retained austenite.
For steel J, the isothermal holding temperatures (300-400 °C) were above the Ms of the steel. Therefore, during this austempering bainitic transformation took place – primarily carbide free bainite formed causing carbon enrichment in austenite. After isothermal holding, on cooling the blanks to room temperature, some martensite formed and certain amount of austenite remained untransformed due to carbon enrichment during austempering.

[0089] From Tables 2-4, it is evident that due to the described different multiphase microstructures both the total elongation and bending angle of the steels in the innovative processes are improved in comparison with the reference conditions, and most importantly these are higher than reference values for steel I (Table 3) which is standard 22MnB5 steel subjected to standard hot forming thermal cycle in its reference condition. This is beneficial for enhanced energy absorption capacity of the hot stamped steels in use.

Amended CLAIMS for PCT/EP2017/080359, filed on 2019-02-04 (clean)

1. A method for hot-forming a steel blank into an article comprising the steps of:
   a. heating a steel blank to a temperature T1 and holding the heated blank at T1 during a time period t1, wherein T1 is in the range of Ac1 to Ac3+200 °C and wherein t1 is at most 12 minutes,
   b. transferring the heated blank to a hot-forming tool during a transport time t2 during which the temperature of the heated blank decreases from temperature T1 to a temperature T2, wherein T2 is above Ar1 and wherein the transport time t2 is at most 12 seconds,
   c. forming the blank in the hot-forming tool into an article and quenching it in the hot-forming tool from a temperature T2 to a temperature T3 at a cooling velocity V2 of 25 °C/s or more,
   d. isothermal holding the article at a temperature T4 for a time period t4,
   e. wherein temperature T3 and/or temperature T4 is between Ms and Mf and wherein t4 is more than 10 seconds and less than 10 minutes,
   f. cooling the article from temperature T4 to room temperature at a cooling velocity V4,

   wherein
   1. T3 is between Ms and Mf and wherein T4 is between Bs and Ms, or
   2. T3 is between Bs and Ms and wherein T4 is between Ms and Mf, or
   3. both T3 and T4 are between Ms and Mf, and preferably T3 and T4 are the same,

   and wherein the microstructure of the hot-formed article is a complex phase microstructure consisting of, by volume fraction (vol.%) (sum up to 100)
   - at least 80 vol.% bainite and tempered martensite, wherein the tempered martensite is less than 50 vol.%, preferably equal or less than 40 vol.%, more preferably equal or less than 30 vol.%, and
   - at most 20 vol.% ferrite and/or martensite, and/or retained austenite.

2. Method according to claim 1, wherein the article is held at temperature T3 during a holding time t3 of 1 to 180 seconds.

3. Method according to claim 1, possibility 1, wherein the article is heated from temperature T3 to temperature T4 at a velocity V3 of at least 15 °C/s, preferably at least 20 °C/s, more preferably at least 30 °C/s.

4. Method according to claim 1, possibility 2, wherein the article is cooled from temperature T3 to temperature T4 at a velocity t3 of at most 15 °C/s, preferably at most 10 °C/s, more preferably at most 8 °C/s.

5. Method according to any one of the preceding claims, wherein the article is cooled from temperature T4 to room temperature at a cooling velocity V4, in the range of 0.1-20 °C/s, preferably in the range of 1 - 15 °C/s, more preferably in the range of 2 - 10 °C/s.

6. Method according to anyone of the preceding claims, wherein T1 is in the range of Ac1 to Ac3+150, preferably Ac1 to Ac3+100, more preferably in the range of Ac3-50 to Ac3+50, and wherein t1 is preferably at most 10 minutes, more preferably t1 is in the range of 2-8 min, and wherein the steel blank is heated with a heating velocity V1 in the range of 10-25 °C/s.

7 Method according to any one of the claims 1-6, wherein the steel blank comprises in wt%:

C: 0.10-0.50, preferably 0.15-0.40, more preferably 0.15-0.35,
Mn: 0.50-4.00, preferably 1.00-3.00 more preferably 1.00-2.50,
Si: $\leq$2.0; preferably 0.1-2.0, more preferably 0.1-1,6,
Al: $\leq$2.0, preferably $\leq$1.0, more preferably $\leq$ 0.5,
Cr: $\leq$1.5, preferably $\leq$ 1.2, more preferably 0.001-1.1,
Ti: $\leq$0.10, preferably $\leq$0.05, more preferably $\leq$0.04,
B: $\leq$0.008, preferably $\leq$0.005,
Nb: $\leq$0.10, preferably $\leq$0.05, more preferably 0.001-0.05,

and optionally one or more of the elements selected from

V: $\leq$0.2, preferably $\leq$0.1
Ca: $\leq$0.003, preferably 0.0003-0.003,
N: $\leq$0.005, preferably $\leq$0.003,
P: $\leq$0.015,
S: $\leq$ 0.03, preferably <0.01.
Mo:$\leq$0.5, preferably $\leq$0.05,
Cu: $\leq$1.0,
Ni: $\leq$1.0,

the remainder being Fe and unavoidable impurities.

8. Method according to any one of the claims 1-7, wherein the blank, is provided with a zinc based coating or an aluminium based coating or an organic based coating or any other coating designed to reduce oxidation and/or decarburisation during the hot forming process.

9. Method according to claim 8, wherein the zinc based coating is a coating containing 0.5 - 3.8 wt% Al, 0.5-3.0 wt% Mg, optionally at most 0.2 wt% of one or more additional elements, unavoidable impurities, the balance being zinc.

10. Hot-formed steel article obtained by the method according to any one of the claims 1 - 6, 8 or 9, wherein
the steel comprises in wt%:
C: 0.10 - 0.50,
Mn: 1.00 - 3.00
Si: ≤ 2.0;
Al: ≤ 2.0,
Cr: ≤ 1.5,
Ti: ≤ 0.10,
B: ≤ 0.008,
Nb: ≤ 0.10,
and optionally one or more of the elements selected from
V: ≤ 0.2,
Ca: ≤ 0.003,
N: ≤ 0.005,
P: ≤ 0.015,
S: ≤ 0.03,
Mo: ≤ 0.5,
Cu: ≤ 1.0,
Ni: ≤ 1.0,
the remainder being Fe and unavoidable impurities,
wherein the article has a YS of at least 600 MPa, and a UTS of at least 1000 MPa, and wherein the article has a total elongation (TE) of at least 6% and a bending angle (BA) of at least 45 °.

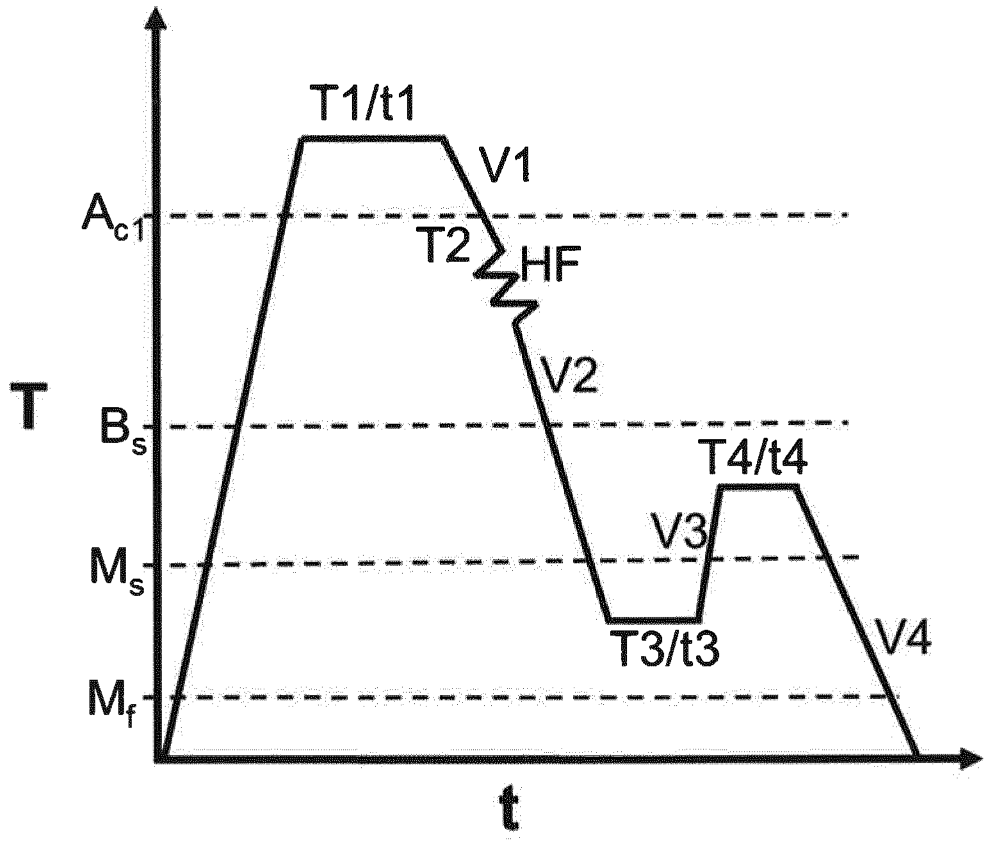

Figure 1

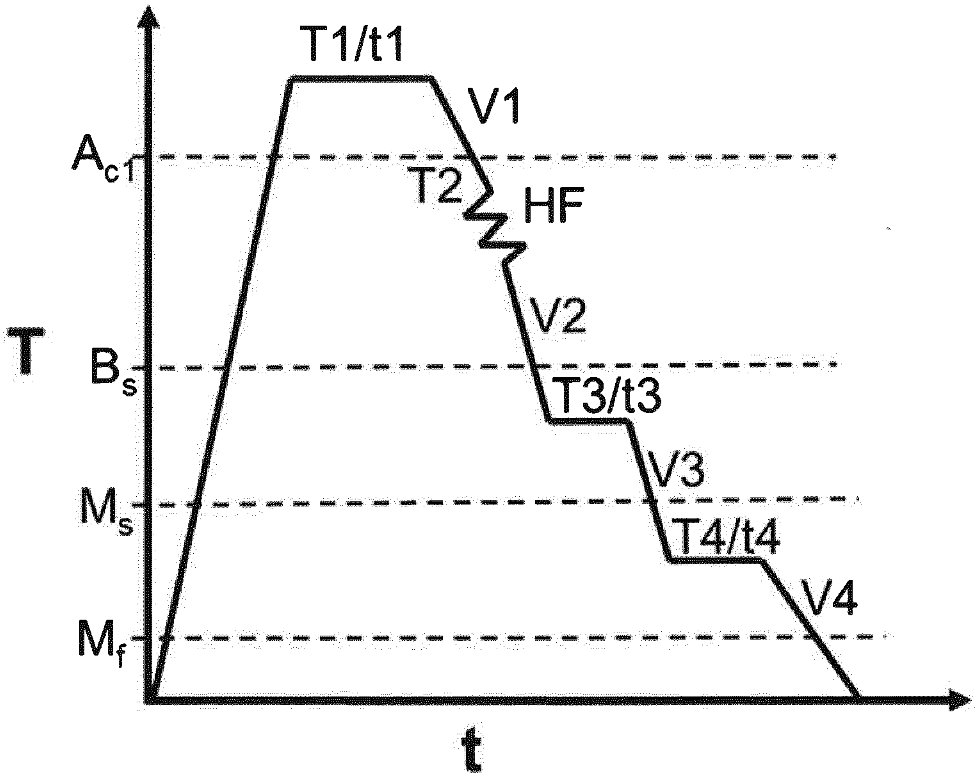

Figure 2

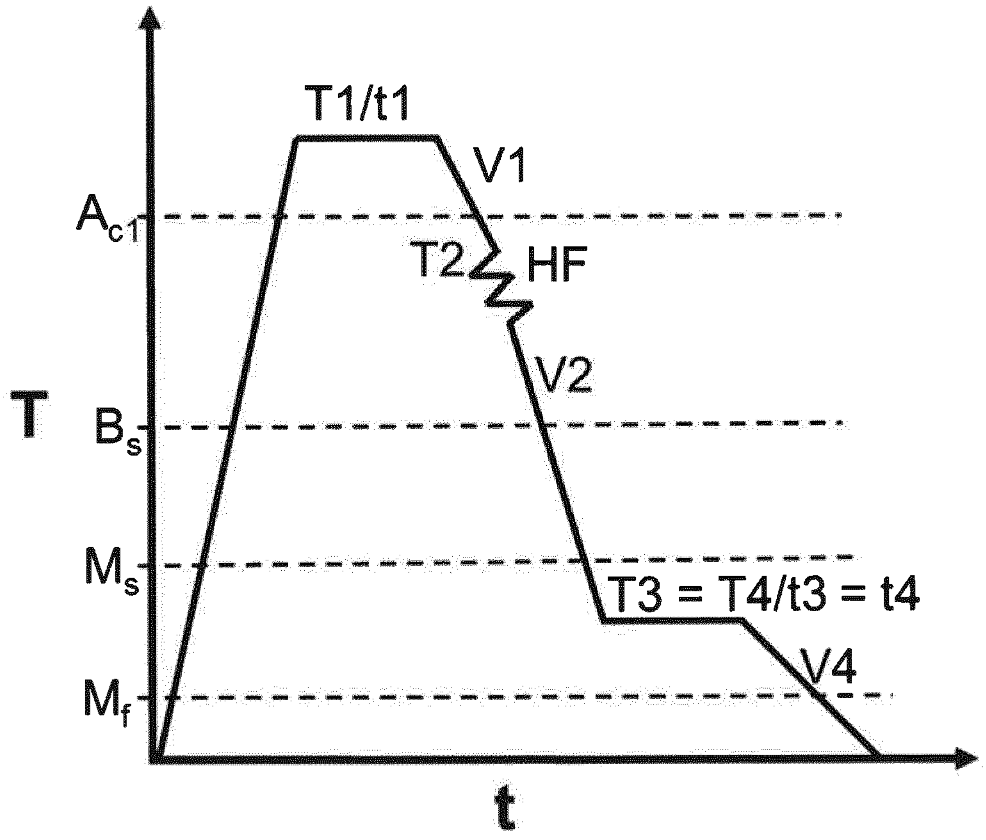

Figure 3

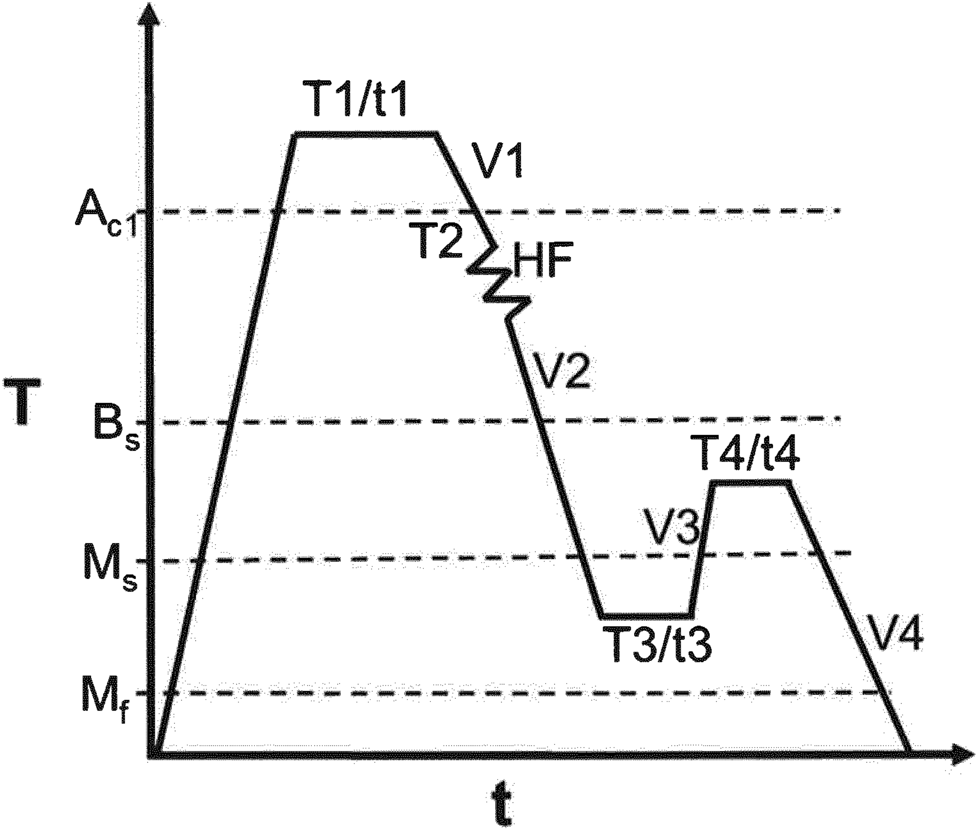

Figure 1