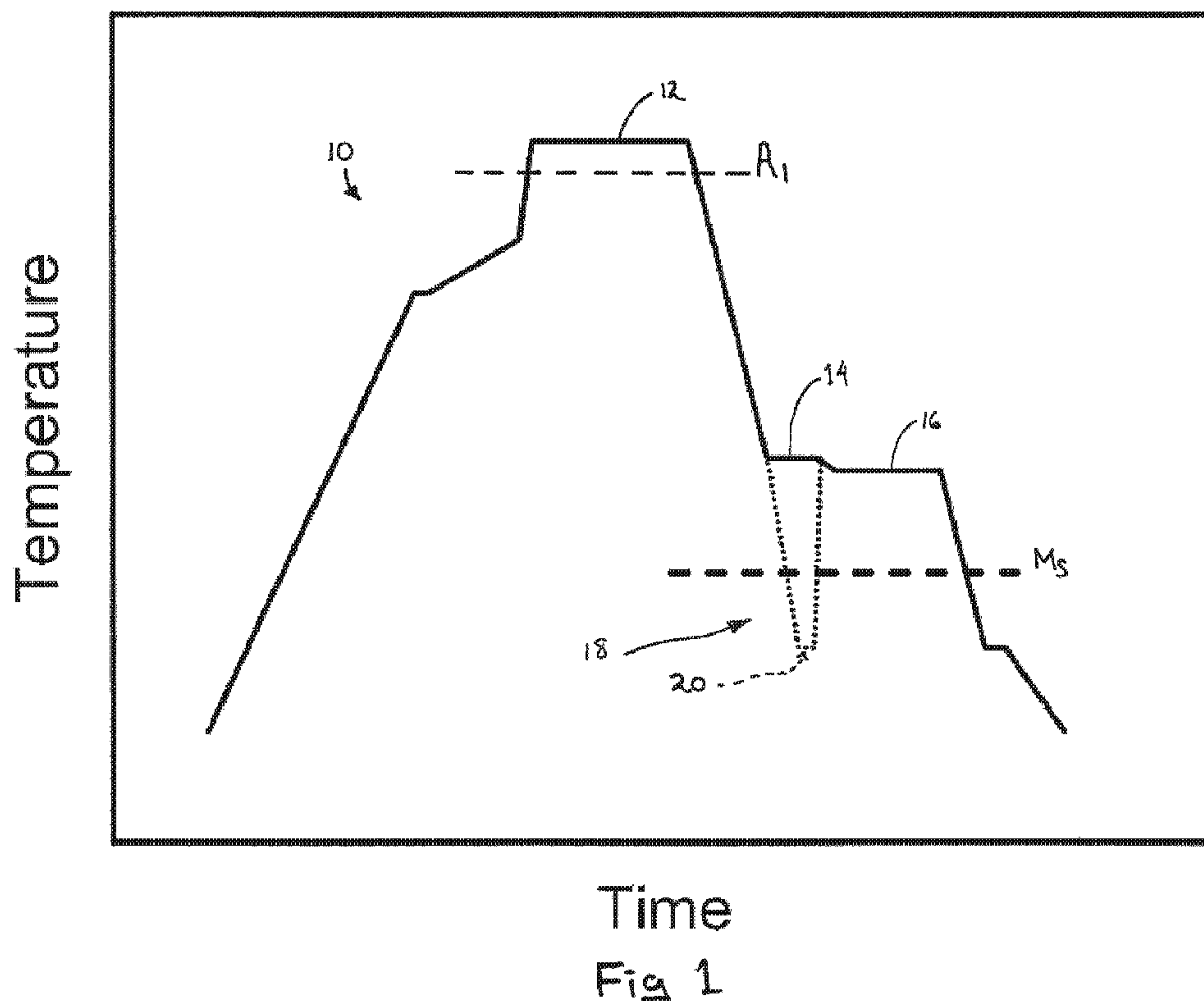




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(57) Abrégé/Abstract:

A method for processing a dual phase steel sheet. The method includes heating the steel sheet to a first temperature (T1), cooling the steel sheet to a second temperature (T2), transitioning the steel sheet to a third temperature (T3), and cooling the steel sheet to



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room temperature. T1 is at least above the temperature at which the steel sheet transforms to austenite and ferrite. T2 is below the martensite start temperature (Ms). The cooling rate to T2 is sufficiently rapid to transform at least some austenite to martensite.

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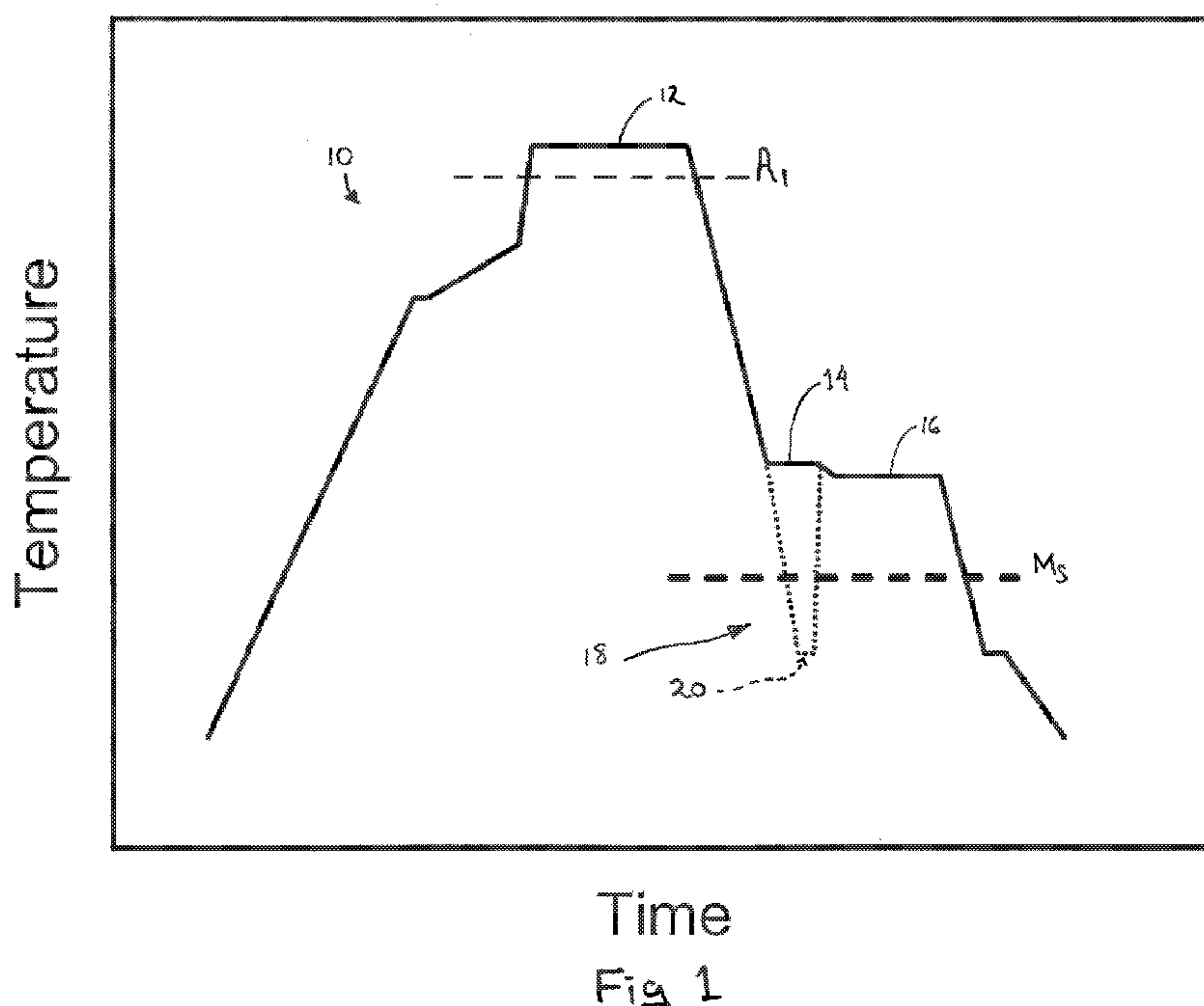
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Time
Fig 1

(57) Abstract: A method for processing a dual phase steel sheet. The method includes heating the steel sheet to a first temperature (T1), cooling the steel sheet to a second temperature (T2), transitioning the steel sheet to a third temperature (T3), and cooling the steel sheet to room temperature. T1 is at least above the temperature at which the steel sheet transforms to austenite and ferrite. T2 is below the martensite start temperature (Ms). The cooling rate to T2 is sufficiently rapid to transform at least some austenite to martensite.

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Dual Phase Steel with Improved Properties

BACKGROUND

[0001] It is desirable to produce steels with high strength and good formability characteristics. The present invention relates to steel compositions and processing methods for production of steel using thermal processing techniques such that the resulting steel exhibits high strength and/or cold formability.

SUMMARY

[0002] The present steel is produced using a composition and a modified thermal process that together produces a resulting microstructure consisting of generally ferrite and a second phase generally comprising martensite and bainite (among other constituents). To achieve such a microstructure, the composition includes certain alloying additions and the thermal process includes a hot-dip galvanizing/galvannealing (HDG) or other thermal process with certain process modification.

BRIEF DESCRIPTION OF THE FIGURES

[0003] The accompanying figures, which are incorporated in and constitute a part of this specification, illustrate embodiments, and together with the general description given above, and the detailed description of the embodiments given below, serve to explain the principles of the present disclosure.

[0004] FIGURE 1 depicts a schematic view of a HDG temperature profile with a quenching step performed prior to galvanizing/galvannealing.

[0005] FIGURE 2 depicts the HDG temperature profile of FIGURE 1, with the average cooling rate of the HDG temperature profile shown in phantom.

[0006] FIGURE 3 depicts a schematic view of an alternative HDG temperature profile with a quenching step performed after galvanizing/galvannealing.

DETAILED DESCRIPTION

[0007] FIG. 1 shows a schematic representation of a combination of a typical hot-dip galvanizing thermal profile and a modified hot-dip galvanizing thermal profile. The modified thermal cycle is used to achieve high strength and good formability in a dual phase steel sheet (described in greater detail below). In a steel sheet used with the two thermal cycles shown in FIG. 1, the steel sheet generally comprises two phases after the thermal cycles – a first phase of predominantly ferrite and a second phase. It should be understood that the term “second phase” used herein is generally used to refer to a phase generally comprising predominately martensite with some bainite. However, it should also be understood that such a second phase may also include any one or more of cementite and/or residual austenite. Additionally, it should be understood that while FIG. 1 is shown in connection with hot-dip galvanizing, in other embodiments a galvannealing or other hot-dip coating process can be used. In still other embodiments, hot-dip coating processes are omitted entirely and the steel sheet is merely subjected to the thermal profile as shown.

[0008] The solid line in FIG. 1 shows a schematic view of the typical hot-dip galvanizing or galvannealing thermal profile (10). As can be seen, the typical thermal profile (10) involves heating the steel sheet to a peak metal temperature (12) and optionally holding the steel sheet at the peak metal temperature (12) for a first predetermined period of time. In the present example, the peak metal temperature (12) is at least above the austenite transformation temperature (A_1) (e.g., dual phase austenite + ferrite region). Thus, at the peak metal temperature (12) at least a portion (by volume) of the steel will be transformed to a combination of austenite and ferrite. Although FIG. 1 shows that peak metal temperature as being solely above A_1 , it should be understood that in some embodiments the peak metal temperature may also include temperatures above the temperature at which ferrite completely transforms to austenite (A_3) (e.g., the single phase, austenite region).

- [0009] As stated above, in the typical thermal profile (10) the steel sheet is held at the peak metal temperature (12) for a first predetermined amount of time. It should be understood that the particular amount of time that the steel sheet is held at the peak metal temperature (12) may be varied by a number of factors such as the particular chemistry of the steel sheet, or the desired volumetric quantity of the second phase in the steel sheet at the conclusion of the thermal cycle. Additionally, in some circumstances the time held at the peak metal temperature (12) may be reduced to zero or near zero. In circumstances where the hold time is reduced, the peak metal temperature can be increased to compensate for such a reduction.
- [0010] Once the first predetermined period of time has elapsed, the typical thermal profile (10) involves rapidly cooling the steel sheet to an intermediate temperature (14). The steel sheet is then held at the intermediate temperature (14) for a second predetermined period of time. Generally, the steel sheet is held at the intermediate temperature (14) for a sufficient amount of time to permit the steel sheet to reach a temperature that is near the temperature of the zinc bath.
- [0011] Still referring to the typical thermal profile (10), the steel sheet is next inserted into a liquid zinc galvanizing tub or galvannealing apparatus. During this stage, the temperature of the steel sheet is slightly reduced to a bath temperature (16) that is below the intermediate temperature (14). The bath temperature (16) is generally below the intermediate temperature (14) to avoid dross formation upon entry of the steel sheet into the liquid zinc.
- [0012] The steel sheet remains at the bath temperature (16) for the duration of the galvanizing. Where galvannealing is used, the steel sheet is removed from the bath at some period of time and then elevated to an annealing temperature. The particular temperature of the bath temperature (16) is at least above the melting point of zinc (e.g., 419° C, 787° F). However, it should be understood that in some examples the bath temperature (16) may be even higher depending on the particular configuration of the galvanizing bath or galvannealing apparatus. It should be also understood that in circumstances where the bath temperature (16)

is higher relative to the melting point of zinc, the intermediate temperature (14) may remain the same as shown, be correspondingly raised, or even lowered.

[0013] At the conclusion of the galvanizing or galvanealing process, the steel sheet is cooled below the martensite start temperature (M_s), thereby transforming at least some austenite into martensite. Of course, as described above, other constituents may form such as bainite, pearlite, or retained austenite. These constituents, along with the formation of martensite, form what is collectively described herein as the second phase. As described above, although the second phase may contain one or more of martensite, bainite, pearlite and/or retained austenite, it should be understood that the second phase is generally characterized by formation of predominately martensite.

[0014] In some instances, modification to the typical thermal profile (10) described above is desirable. For example, because of the galvanizing or galvannealing step in the typical thermal profile (10), the average cooling rate from the peak metal temperature (12) to the martensite start temperature (M_s) may be insufficient to form a desirable volumetric quantity of martensite – instead forming non-martensitic transformation products (e.g., bainite, cementite, pearlite, and/or etc.). This may be the case regardless of how quickly the steel sheet is cooled after galvanizing or galvannealing. To account for this relatively slow average cooling rate, conventional dual phase steels used in such a process often includes high alloy content to increase hardenability and thereby avoid formation of non-martensitic transformation products. However, relatively high alloying additions may be undesirable due to increased cost and reduced mechanical properties. Thus, it can be desirable to modify the typical thermal profile (10) described above to maintain a desired amount of martensite in dual phase steels without high alloying additions. Further modifications described below, such as reheating from below the martensite start temperature (M_s) to the intermediate temperature (14), may additionally be desirable to improve mechanical properties such as hole expansion ratio (HER) or yield strength (regardless of the particular amount of alloying additions).

- [0015] In the present embodiments of the modified thermal profile, improvements to the mechanical properties were more significant than expected, especially when considering the relatively short tempering time (e.g., duration of time during which the steel sheet is exposed to the zinc bath).
- [0016] As shown in FIG. 1, the typical thermal profile (10) described above can be modified to include a quench step (18) prior to the galvanizing or galvannealing step described above. As can be seen, this alternative procedure is generally identical to the procedure described above with the exception of the portion of the procedure related to the intermediate temperature (14). In particular, instead of quenching the steel sheet from the peak metal temperature (12) to the intermediate temperature (14), the steel sheet is quenched from the peak metal temperature (12) to a quench temperature (20). It should be understood that the cooling rate from the peak metal temperature (12) to the quench temperature (20) is generally high enough to transform at least some of the austenite formed at the peak metal temperature (12) to martensite. In other words, the cooling rate is rapid enough to transform austenite to martensite instead of other non-martensitic transformation products such as ferrite, pearlite, or bainite which form at relatively lower cooling rates.
- [0017] In the present example, the quench temperature is below the martensite start temperature (M_s). The difference between the quench temperature (20) and the martensite start temperature (M_s) can vary depending on the individual composition of the steel sheet being used. However, in many embodiments the difference between quench temperature (20) and M_s is sufficiently great to form a predominately martensitic second phase.
- [0018] Once the quench temperature (20) is reached, the temperature of the steel sheet is maintained at the quench temperature for a predetermined quench time. Because formation of martensite is nearly instantaneous, the particular amount of time during which the steel sheet is at the quench temperature is generally insignificant.

- [0019]** After quenching to the quench temperature (20), the steel sheet is reheated to the intermediate temperature (14) or to another temperature at or near the bath temperature (16). In the present example, reheating is relatively quick and may be performed using various methods such as induction heating, torch heating, and/or other methods known in the art. Once reheated, the steel sheet is inserted into a zinc bath. In the zinc bath, the steel sheet will reach the bath temperature (16), as described above, where the steel sheet will remain for the remainder of the galvanizing. The particular amount of time during which the steel sheet is in the zinc bath is largely determined by the galvanizing/galvannealing process. However, it should be understood that during this time, the martensite is tempered to thereby improve the mechanical properties of the steel sheet. Where a galvannealing process is used, the steel sheet may be heated to an annealing temperature after removal from the bath.
- [0020]** Although the reheating step is described herein as being in connection with a coating step, such as galvanizing or galvannealing, it should be understood that no such limitation is intended. For instance, in some examples the reheating step may merely be performed and then the process may proceed as described below. In such examples, the steel sheet is held at the intermediate temperature (14) or the bath temperature (16) despite not actually being subjected to a galvanizing or galvannealing treatment. Additionally, in some examples the steel sheet may be held at a lower temperature (e.g., 400° C) relative to the bath temperature (16) because heating the steel sheet to the melting point of zinc is not necessary without application of zinc. The steel sheet may be held at such a temperature for any suitable time as will be apparent to those of ordinary skill in the art in view of the teachings herein.
- [0021]** Once the galvanizing, galvannealing, or other similar thermal process is completed, the steel sheet is cooled to room temperature, as similarly described above. Accordingly, in the present example, the steel sheet is first heated to a peak metal temperature (12) to form austenite and optionally ferrite. Next the steel sheet is cooled from the peak metal temperature (12) to the quench

temperature (20) to form martensite or other constituents of the second phase. After quenching, the steel sheet is reheated to approximately the zinc bath temperature for galvanizing and optionally galvannealing. Finally, the steel sheet is cooled to ambient temperature.

[0022] FIG. 2 shows a comparison of the average cooling rate (30) of the typical thermal profile (10) versus the average cooling rate (32) of the typical thermal profile (10) modified to include the quench step (18). As can be seen, the quench step (18) substantially reduces the average cooling rate of the typical thermal profile (10). In examples where the method described herein is used in a continuous galvanizing/galvannealing line, average cooling rate may depend at least partially on the feed speed of the galvanizing/galvannealing line. For instance, where feed speeds of about 30 meters per minute are used, the average cooling rate using the typical thermal profile (10) is about 17° C per second, while the average cooling rate using the modifications described herein is about 48° C per second. In examples where feed speeds of about 91 meters per minute are used, the average cooling rate using the typical thermal profile (10) is about 6° C per second, while the average cooling rate using the modifications described herein is about 16° C per second. In yet other examples where feed speeds of about 120 meters per minute are used, the average cooling rate using the typical thermal profile (10) is about 4° C per second, while the average cooling rate using the modifications described herein is about 12° C per second.

[0023] Regardless of the particular cooling rate achieved, it should be understood that improved mechanical properties of the steel sheet can be achieved by reheating the steel sheet as described above. These improvements can be achieved whether the steel sheet includes conventional dual-phase alloy compositions or compositions with relatively low alloying elements described herein.

[0024] In embodiments where reduced cooling rates are achieved, it should be understood that because of the reduction in the average cooling rate, martensite is more readily formed when the quench step (18) is added to the typical thermal profile (10). Since the conditions increase the propensity to form martensite, less

alloying elements are required in the steel sheet. Thus, when the quench step (18) is applied to the typical thermal profile (10) described above, dual phase steel can be galvanized or galvanized with substantially less alloying elements. Despite having less alloying elements, the steel sheet can have similar post heat treatment martensite content as conventional dual phase steels treated using only the typical thermal profile (10).

[0025] It should be understood that in some examples it may be desirable to modify the typical thermal profile (10) such that the quench step (18) is performed after galvanizing/galvannealing instead of before. One such example can be seen in FIG. 3. In FIG. 3, the quench step (18) may be performed as similarly described above with a rapid cooling of the steel sheet below the martensite start temperature (M_s). When the quench step (18) is performed after galvanizing or galvanized as shown in FIG. 3, the average cooling rate from the peak metal temperature (12) to the intermediate temperature (14) or bath temperature (16) is similar to the average cooling rate (30) for the typical thermal profile (10) shown in FIG. 2. Because this is a relatively low cooling rate, it should be understood that martensite formation will be reduced as similarly encountered in the typical thermal profile (10). With less martensite formation, higher alloying elements may be required to achieve desirable levels of martensite. Thus, applying the quench step (18) after galvanizing or galvanized will not achieve cost savings associated with reduced alloying content. However, applying the quench step (18) after galvanizing or galvanized will still nonetheless promote improved mechanical properties such as hole expansion ratio (HER) and yield strength. In some examples, these improvements to the mechanical properties of the steel sheet can be comparable to those improvements achieved through applying the quench step (18) prior to galvanizing or galvanized.

[0026] In some variations of the process where the quench step (18) is applied after galvanizing or galvanized, a tempering step (40) may also be performed, where the steel sheet is heated to a predetermined temperature above or below the martensite start temperature (M_s) for a predetermined period of time after the

quench step (18). When such a tempering step is used, the average cooling rate is also similar to the average cooling rate (30) for the typical thermal profile (10) shown in FIG. 2. Thus, high alloy content will still be required to form a predominantly martensitic second phase. However, such a tempering step further improves mechanical properties such as hole expansion ratio (HER) and yield strength.

[0027] The steel sheet may include various alloying elements typically present in conventional dual phase steels. For instance, in some embodiments, carbon provides increased strength. For instance, increasing carbon concentration generally lowers the M_s temperature, lowers transformation temperatures for other non-martensitic constituents (e.g., bainite, ferrite, pearlite), and increases the time required for non-martensitic products to form. Additionally, increased carbon concentrations may improve the hardenability of the material thus retaining formation of non-martensitic constituents near the core of the material where cooling rates may be locally depressed. However, it should be understood that carbon additions may be limited as significant carbon concentrations can lead to detrimental effects on weldability. Furthermore, in greater concentrations carbon can have a detrimental effect of formability. Therefore, the carbon content is generally kept around 0.067- 0.14% by weight.

[0028] In some embodiments manganese provides increased strength by lowering transformation temperatures of other non-martensitic constituents and increasing the amount of martensite. Manganese can further improve the propensity of the steel sheet to form martensite by increasing hardenability. Manganese can also increase strength through solid solution strengthening. However, the presence of manganese in large concentrations can degrade formability. Therefore the manganese content is generally present in the concentration of about 1.65-2.9% by weight.

[0029] In some embodiments aluminum additions are made to provide deoxidization. However, aluminum additions beyond certain levels can lead to formability being

degraded. Accordingly, aluminum is generally present in the concentration of about 0.015-0.07% by weight.

[0030] In some embodiments silicon can be added to promote a dual phase structure consisting of predominately ferrite and martensite. However, when silicon is increased beyond certain concentrations, zinc will not adhere as effectively to the steel sheet. Accordingly, silicon is generally present in the concentration of about 0.1-0.25% by weight.

[0031] In some embodiments niobium is added to refine ferrite grains. Such grain refinement is desirable to improve formability and improve weld quality. However, if niobium concentrations exceed a certain amount, formability of the steel sheet will degrade. Accordingly, niobium is generally present in the concentration of about 0-0.045% by weight. Alternatively, in some examples niobium is present in the concentration of about 0.015-0.045% by weight.

[0032] In some embodiments vanadium is added to increase hardenability and/or refine ferrite grains. When added, vanadium is generally included in a concentration less than or equal to 0.05% by weight.

[0033] In some examples chromium is added to improve formability and weld quality. However, chromium additions exceeding certain concentrations will result in low quality surface properties. Accordingly, chromium may be included in the concentration of about 0-0.67%, or 0.2-0.67% by weight.

[0034] In other embodiments molybdenum may be used to increase hardenability. When molybdenum is used, molybdenum can be included in a concentration of about 0.08-0.45% by weight. In other embodiments the lower limit concentration of molybdenum is reduced further, or even eliminated entirely.

[0035] In some embodiments titanium and boron are added to increase strength. It should be understood that in some embodiments titanium and boron may be used together, separately in lieu of the other, or neither element may be used. When titanium is used, titanium is present in the concentration of about 0.01-0.03% by

weight. When boron is used, boron is present in the concentration of about 0.0007-0.0013% by weight.

[0036] In embodiments where titanium and boron are added together, titanium is generally present in suitable concentrations to substantially prevent boron from forming nitrides. Thus, titanium may be included to combine with nitrogen prior to the nitrogen combining with boron. In some circumstances titanium is included in concentrations of about 3.43 times the weight percent of nitrogen. When included in this concentration, titanium generally combines with nitrogen, thereby preventing boron from forming nitrides.

[0037] In other embodiments, variations in the concentrations of elements and the particular elements selected may be made. Of course, where such variations are made, it should be understood that such variations may have a desirable or undesirable effect on the steel sheet microstructure and/or mechanical properties in accordance with the properties described above for each given alloying addition.

EXAMPLE 1

[0038] Embodiments of the steel sheet were made with the compositions set forth in Table 1 below.

Table 1 Chemical compositions in weight %.

Cast Code	C		Mn		Al		Si		Nb		V		Cr		Mo		Ti		B	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
A	0.08	0.10	1.70	1.90	0.03	0.06	0.15	0.25	0.015	0.025	-	0.010	0.20	0.30	-	0.02	0.01	0.03	-	0.001
B	0.067	0.08	1.65	1.82	0.02	0.07	0.15	0.25	-	0.001	0.030	0.050	-	-	0.16	0.20	0.01	0.02	-	0.001
C	0.10	0.12	2.10	2.30	0.03	0.06	0.15	0.25	-	0.003	-	0.010	0.20	0.30	0.25	0.35	-	0.003	-	0.001
D	0.10	0.12	1.75	1.90	0.02	0.07	0.15	0.25	0.035	0.045	-	0.008	0.20	0.30	0.15	0.20	0.01	0.020	-	0.001
E	0.11	0.13	2.40	2.70	0.03	0.06	0.15	0.25	-	0.004	-	0.008	0.30	0.40	0.35	0.45	-	0.005	-	0.0007
F	0.08	0.10	2.00	2.20	0.03	0.07	0.40	0.50	0.040	0.060	-	0.008	0.20	0.30	0.30	0.40	-	0.008	-	0.001
G	0.09	0.10	2.25	2.42	0.015	0.07	0.10	0.20	0.035	0.045	-	0.008	0.57	0.67	0.08	0.12	-	0.030	0.0007	0.0013
H	0.12	0.14	2.70	2.90	0.03	0.06	0.15	0.25	-	0.004	-	0.008	0.30	0.40	0.35	0.45	-	0.005	-	0.0007
I	0.11	0.13	2.45	2.60	0.015	0.05	0.42	0.58	0.035	0.045	-	0.020	0.57	0.63	-	0.05	0.015	0.025	0.0012	0.002

EXAMPLE 2

[0039] Embodiments of the steel sheet made with the compositions set forth above in Table 1 were subjected to mechanical testing. Mechanical properties for a selected number of the compositions set forth in Table 1 are set forth below in Table 2.

Table 2 Mechanical properties for selected compositions of Table 1.

Example of Cast Code	Alloy No.	Quench Temperature (°C)	YPE (%)	YS (MPa)	UTS (MPa)	TE (%)	HER (%)	Note
D		Not applicable	0	420	780	15	20	Comparative Example
D	4	250	1.4	690	780	15	60	
G		Not applicable	0	650	980	11	20	Comparative Example
F	6	250	1	840	980	13	50	
I		Not applicable	0	800	1180	8	-	Comparative Example
I	9	250	2.4	1120	1165	10	55	

EXAMPLE 3

[0040] Embodiments of the steel sheet were made with the compositions set forth in Table 3 below. The particular compositions shown in Table 3 are based on the compositional ranges set forth in Table 1.

Table 3 Chemical compositions in weight %.

Alloy No.	Example of Cast Code	Al	B	C	Ca	Cr	Cu	Mn	Mo	N	Nb	Ni	P	S	Si	Sn	Ti	V
1	C w/o Mo	0.042	0.0005	0.094	<0.0003	0.25	<0.003	2.19	<0.003	0.0004	<0.003	<0.003	<0.003	0.0004	0.19	<0.003	<0.003	<0.003
2	C	0.037	0.0004	0.093	<0.0003	0.25	<0.003	2.27	0.3	0.0005	<0.003	<0.003	0.003	0.0006	0.18	<0.003	<0.003	<0.003
3	D w/o Mo	0.041	0.0004	0.1	<0.0003	0.25	<0.003	1.86	<0.003	0.0012	0.042	<0.003	<0.003	0.0004	0.2	<0.003	0.015	<0.003
4	D	0.039	0.0004	0.1	<0.0003	0.25	<0.003	1.87	0.18	0.0011	0.042	<0.003	<0.003	0.0002	0.2	<0.003	0.015	<0.003
5	F w/o Mo	0.046	0.0004	0.087	<0.0003	0.25	<0.003	2.04	<0.003	0.001	0.053	<0.003	<0.003	0.0005	0.43	<0.003	<0.003	<0.003
6	F	0.044	0.0004	0.086	<0.0003	0.25	<0.003	2.09	0.35	0.001	0.053	<0.003	<0.003	0.0005	0.43	<0.003	<0.003	<0.003
7	G w/o Mo	0.037	0.0012	0.092	<0.0003	0.61	<0.003	2.24	<0.003	0.0004	0.04	<0.003	<0.003	0.0005	0.14	<0.003	<0.003	<0.003
8	G	0.036	0.0013	0.091	<0.0003	0.61	<0.003	2.26	0.096	0.0004	0.043	<0.003	<0.003	0.0004	0.15	<0.003	<0.003	<0.003
9	H w/o Mo	0.043	0.0006	0.13	<0.0003	0.35	<0.003	2.76	<0.003	0.0006	<0.003	<0.003	<0.003	0.0004	0.19	<0.003	<0.003	<0.003
10	H	0.04	0.0005	0.13	<0.0003	0.34	<0.003	2.72	0.4	0.0008	<0.003	<0.003	<0.003	0.0004	0.19	<0.003	<0.003	<0.003
11	I w/o Cr	0.029	0.0025	0.12	0.0003	<0.003	<0.003	2.47	<0.003	0.0008	0.042	<0.003	<0.003	0.0004	0.49	<0.003	0.021	<0.003
12	I	0.028	0.0026	0.12	0.0003	0.58	<0.003	2.48	<0.003	0.0011	0.045	<0.003	<0.003	0.0005	0.49	<0.003	0.021	<0.003

EXAMPLE 4

[0041] Embodiments of the steel sheet made with the compositions set forth above in Table 3 were subjected to mechanical testing. Mechanical properties for each of the compositions set forth in Table 3 are set forth below in Tables 4 through 15.

Table 4 Mechanical properties for alloy no. 1 of Table 3.

Alloy No.	Temper ature 1 (°C)	Time at Temper ature 1 (s)	Temper ature 2 (°C)	Time at Temper ature 2 (s)	Temper ature 3 (°C)	Time at Temper ature 3 (s)	UY S(MPa)	LYS (MPa)	YPE (%)	EUL Stress @ 0.5% (MPa)	0.2% OYS(MPa)	UTS(M Pa)	Unifor m Elongat ion(%)	TotalEl ongatio n (%)	Hardne ss (HRA)	Hole Expans ion Ratio (%)	Note
1	800	180	250	30	466	50				562	556	726	8	14	-	61	
1	800	180	250	30	466	50				522	526	699	9	16	-	61	
1	800	180	250	30	466	100				489	474	677	9	18	-	88	
1	800	180	250	30	466	100				389	378	643	15	23	-	88	
1	800	180	250	30	466	100				498	485	678	10	19	-	88	
1	800	180	250	30	466	120				467	450	665	10	17	-	75	
1	800	180	250	30	466	120				471	454	664	10	14	-	75	
1	800	180	250	60	466	40				465	475	660	10	17	58	65	
1	800	180	250	120	466	80				480	453	665	10	16	55	95	
1	800	180	SKIP	SKIP	466	50				392	384	649	14	22	-	55	Comparative
1	825	180	250	60	466	40				577	570	728	8	13	55	81	
1	825	180	250	120	466	80				664	668	767	5	10	59	102	
1	850	180	250	30	466	50				762	772	848	5	8	-	109	
1	850	180	250	30	466	50				736	745	823	5	9	-	109	
1	850	180	250	30	466	100				763	768	834	5	8	-	102	
1	850	180	250	30	466	100				759	768	832	5	8	-	102	
1	850	180	250	30	466	120				725	731	805	5	8	-	110	
1	850	180	250	30	466	120				735	742	809	4	8	-	110	
1	850	180	250	60	466	40				868	870	915	5	9	62	91	
1	850	180	250	120	466	80				819	823	859	4	7	62	96	

Table 5 Mechanical properties for alloy no. 2 of Table 3.

Alloy No.	Temperature 1 (°C)	Time at Temperature 1 (s)	Temperature 2 (°C)	Time at Temperature 2 (s)	Temperature 3 (°C)	Time at Temperature 3 (s)	UY S (MPa)	LYS (MPa)	YPE (%)	EUL Stress @ 0.5% (MPa)	0.2% OYS (MPa)	UTS (MPa)	Uniform Elongation (%)	Total Elongation (%)	Hardness (HRA)	Hole Expansion Ratio (%)	Note
2	800	180	250	30	466	50				577	584	811	9	15	-	49	
2	800	180	250	30	466	50				575	581	813	9	16	-	49	
2	800	180	250	30	466	100				623	628	855	8	14	-	21	
2	800	180	250	30	466	100				583	583	836	8	14	-	21	
2	800	180	250	30	466	120				484	474	850	9	14	-	32	
2	800	180	250	30	466	120				435	418	843	10	15	-	32	
2	800	180	250	60	466	40				673	687	849	7	9	62	27	
2	800	180	250	120	466	80				678	684	857	8	14	62	56	
2	800	180	SKIP	SKIP	466	50				469	457	843	10	16	-	24	Compare
2	800	180	SKIP	SKIP	466	50				459	453	829	10	16	-	24	Compare
2	825	180	250	60	466	40				716	726	855	6	10	63	83	
2	825	180	250	120	466	80				815	824	891	6	11	63	92	
2	850	180	250	30	466	50				891	914	990	5	7	-	86	
2	850	180	250	30	466	50				878	901	975	5	9	-	86	
2	850	180	250	30	466	100				845	864	938	4	7	-	106	
2	850	180	250	30	466	100				836	863	940	4	7	-	106	
2	850	180	250	30	466	120				843	866	943	4	7	-	93	
2	850	180	250	30	466	120				828	845	931	4	8	-	93	
2	850	180	250	60	466	40	977	971	0	969	973	1007	5	9	64	78	
2	850	180	250	120	466	80	951	946	0	949	946	978	5	9	64	104	

Table 6 Mechanical properties for alloy no. 3 of Table 3.

Alloy No.	Temperature 1 (°C)	Time at Temperature 1 (s)	Temperature 2 (°C)	Time at Temperature 2 (s)	Temperature 3 (°C)	Time at Temperature 3 (s)	UY S(MPa)	LYS (MPa)	YPE (%)	EUL Stress @ 0.5% (MPa)	0.2% OYS(MPa)	UTS(MPa)	Uniform Elongation (%)	Total Elongation (%)	Hardness (HRA)	Hole Expansion Ratio (%)	Note
3	800	180	250	30	466	50				606	606	764	9	15	-	51	
3	800	180	250	30	466	50				595	595	756	10	15	-	51	
3	800	180	250	30	466	100				626	628	765	9	13	-	53	
3	800	180	250	30	466	100				609	609	752	8	12	-	53	
3	800	180	250	30	466	120				625	625	766	9	12	-	43	
3	800	180	250	30	466	120				593	595	746	9	13	-	43	
3	800	180	250	60	466	40	619	612	1	613	612	760	10	16	60	52	
3	800	180	250	120	466	80	622	616	1	616	618	745	10	17	59	52	
3	800	180	SKIP	SKIP	466	50				561	559	748	11	15	-	37	Compara
3	800	180	SKIP	SKIP	466	50				579	578	758	11	15	-	37	Compara
3	825	180	250	60	466	40	582	572	1	575	574	732	12	18	59	69	
3	825	180	250	120	466	80	576	568	1	568	570	711	11	18	59	70	
3	850	180	250	30	466	50	679.2	678.7	0.44	672	674	770	8	12	-	66	
3	850	180	250	30	466	50	668.7	663	0.4	667	665	760	9	14	-	66	
3	850	180	250	30	466	100	669.2	651	1.47	658	658	744	9	14	-	67	
3	850	180	250	30	466	100	626.5	620.3	0.73	621	621	728	9	14	-	67	
3	850	180	250	30	466	120	681.9	655.6	1.93	656	657	739	9	13	-	85	
3	850	180	250	30	466	120	654.1	637.9	2.22	638	640	733	8	13	-	85	
3	850	180	250	60	466	40	649	608	3	609	610	698	12	22	59	78	
3	850	180	250	120	466	80	624	594	2	595	595	697	12	20	58	84	
3	850	180	SKIP	SKIP	466	50	580.2	577.4	0.7	580	580	706	12	18	-	89	Compara
3	850	180	SKIP	SKIP	466	50				556	556	697	12	20	-	89	Compara

Table 7 Mechanical properties for alloy no. 4 of Table 3.

All oy No.	Tempera ture 1 (°C)	Time at Tempera ture 1 (s)	Tempera ture 2 (°C)	Time at Tempera ture 2 (s)	Tempera ture 3 (°C)	Time at Tempera ture 3 (s)	UY S(M Pa)	LYS (MP a)	YP E (%)	EU L Stre ss @ 0.5 %	0.2% OYS(M Pa)	UTS(M Pa)	Uniform Elongation (%)	TotalElong ation (%)	Hardn ess (HRA)	Hole Expans ion Ratio (%)	Note
4	800	180	250	30	466	50				711	724	866	7	10	-	36	
4	800	180	250	30	466	50				698	713	855	8	12	-	36	
4	800	180	250	30	466	100				721	734	860	6	7	-	63	
4	800	180	250	30	466	100				717	728	857	5	7	-	63	
4	800	180	250	30	466	120				713	722	863	8	12	-	43	
4	800	180	250	30	466	120				702	707	845	9	12	-	43	
4	800	180	250	60	466	40				705	706	854	8	14	59	34	
4	800	180	250	120	466	80				755	765	877	7	12	62	53	
4	800	180	SKIP	SKIP	466	50				609	615	841	9	14	-	35	Compara
4	800	180	SKIP	SKIP	466	50				606	608	839	10	15	-	35	Compara
4	825	180	250	60	466	40				689	693	820	9	13	60	57	
4	825	180	250	120	466	80				679	679	819	9	15	63	69	
4	850	180	250	30	466	50	720.5	719.	0.1	719	720	814	8	13	-	53	
4	850	180	250	30	466	50				722	726	824	7	11	-	53	
4	850	180	250	30	466	100	705.5	701	0.2	704	705	799	8	12	-	62	
4	850	180	250	30	466	100	710.5	708	0.0	708	710	804	7	10	-	62	
4	850	180	250	30	466	120	720.8	709.	0.0	710	710	796	8	12	-	94	
4	850	180	250	30	466	120	689.6	688.	0.0	689	690	779	8	12	-	94	
4	850	180	250	60	466	40	717	694	1	695	695	785	9	15	59	65	
4	850	180	250	120	466	80	695	675	1	682	682	779	9	15	58	58	
4	850	180	SKIP	SKIP	466	50				626	628	775	10	16	-	63	Compara
4	850	180	SKIP	SKIP	466	50				624	625	771	10	14	-	63	Compara

Table 8 Mechanical properties for alloy no. 5 of Table 3.

All oy No.	Temperat ure 1 (°C)	Time at Temperat ure 1 (s)	Temperat ure 2 (°C)	Time at Temperat ure 2 (s)	Temperat ure 3 (°C)	Time at Temperat ure 3 (s)	UY S(MPa)	LYS (MPa)	Y P E (%)	EU L Stre ss @ 0.5 %	0.2% OYS(MPa)	UTS(MPa)	Uniform Elongation (%)	TotalElong ation (%)	Hardn ess (HRA)	Hole Expans ion Ratio (%)	Note
5	800	180	250	30	466	50	559.2	557.	0.6	561	560	782	12	17	-	-	
5	800	180	250	30	466	50	579.7	579.	0.2	580	580	803	11	16	-	-	
5	800	180	250	30	466	100	575.9	575.	0.2	572	571	803	11	17	-	28	
5	800	180	250	30	466	100	613	612.	0.3	607	607	810	10	14	-	28	
5	800	180	250	30	466	120	565.3	560.	0.8	567	567	785	11	17	-	36	
5	800	180	250	30	466	120	551.1	550.	0.7	557	556	805	10	15	-	36	
5	800	180	250	60	466	40	574	572	1	575	576	788	11	16	60	32	
5	800	180	250	120	466	80				634	634	830	10	15	59	40	
5	800	180	SKIP	SKIP	466	50				493	490	805	11	16	-	34	Compara
5	800	180	SKIP	SKIP	466	50				499	495	788	11	16	-	34	Compara
5	825	180	250	60	466	40				536	536	735	13	18	58	55	
5	825	180	250	120	466	80	541	535	1	538	537	734	11	18	56	55	
5	850	180	250	30	466	50	650.7	626.	0.4	628	628	755	11	17	-	51	
5	850	180	250	30	466	50	559.3	551.	1.6	553	552	735	12	17	-	51	
5	850	180	250	30	466	100	581.7	579.	0.5	580	580	760	11	16	-	66	
5	850	180	250	30	466	100	563	562	0.9	563	563	735	11	17	-	66	
5	850	180	250	30	466	120	609.1	597.	1.3	599	599	757	12	18	-	61	
5	850	180	250	30	466	120	590.4	565.	1.2	586	586	737	11	19	-	61	
5	850	180	250	60	466	40	593	580	1	585	584	731	13	19	57	64	
5	850	180	250	60	466	40	593	580	1	585	584	731	13	19	57	64	
5	850	180	250	120	466	80	564	553	1	553	553	716	12	20	56	49	

Table 9 Mechanical properties for alloy no. 6 of Table 3.

All oy No.	Temperat ure 1 (°C)	Time at Temperat ure 1 (s)	Temperat ure 2 (°C)	Time at Temperat ure 2 (s)	Temperat ure 3 (°C)	Time at Temperat ure 3 (s)	UY S(MP a)	LYS (MP a)	YP E (%)	EU L Stre ss @ 0.5 %	0.2% OYS(M Pa)	UTS(M Pa)	Uniform Elongation (%)	TotalElong ation (%)	Hardn ess (HRA)	Hole Expans ion Ratio (%)	Note
6	800	180	250	30	466	50				593	592	964	8	12	-	30	
6	800	180	250	30	466	50				604	603	975	8	12	-	30	
6	800	180	250	30	466	100				557	552	995	8	12	-	24	
6	800	180	250	30	466	100				554	548	991	8	11	-	24	
6	800	180	250	30	466	120				551	547	972	8	14	-	23	
6	800	180	250	30	466	120				559	556	983	8	13	-	23	
6	800	180	250	60	466	40	793	791	1	793	798	997	8	13	67	23	
6	800	180	250	120	466	80	741	739	0	739	739	987	8	13	65	33	
6	800	180	SKIP	SKIP	466	50				598	613	1003	7	13	-	24	Compara
6	800	180	SKIP	SKIP	466	50				602	618	1002	7	12	-	24	Compara
6	825	180	250	60	466	40	814	812	0	814	815	989	8	12	64	46	
6	825	180	250	120	466	80	885	866	2	879	866	964	9	14	65	53	
6	850	180	250	30	466	50	731.1	710.	1.2	714	715	873	9	16	-	36	
6	850	180	250	30	466	50	724.6	718	1.2	725	725	874	10	16	-	36	
6	850	180	250	30	466	100	685.6	682.	0.8	694	696	899	9	13	-	50	
6	850	180	250	30	466	100	693.8	693	1.0	702	703	899	8	14	-	50	
6	850	180	250	30	466	120	720.6	702.	1.2	706	707	892	9	16	-	43	
6	850	180	250	30	466	120	715.3	706.	1.3	708	708	889	9	15	-	43	
6	850	180	250	60	466	40	792	762	1	782	767	878	9	15	64	62	
6	850	180	250	120	466	80	807	776	2	782	786	893	9	15	62	58	

Table 10 Mechanical properties for alloy no. 7 of Table 3.

All oy No.	Tempera ture 1 (°C)	Time at Tempera ture 1 (s)	Tempera ture 2 (°C)	Time at Tempera ture 2 (s)	Tempera ture 3 (°C)	Time at Tempera ture 3 (s)	UY S(M Pa)	LYS (MP a)	YP E (%)	EU L Stre ss @ 0.5 %	0.2% OYS(M Pa)	UTS(M Pa)	Uniform Elongation (%)	TotalElong ation (%)	Hardn ess (HRA)	Hole Expans ion Ratio (%)	Note
7	800	180	250	30	466	50				688	697	929	8	12	-	36	
7	800	180	250	30	466	50				697	709	941	8	12	-	36	
7	800	180	250	30	466	100				666	678	915	6	9	-	41	
7	800	180	250	30	466	100				719	733	936	7	7	-	41	
7	800	180	250	30	466	120				567	566	928	8	11	-	32	
7	800	180	250	30	466	120				563	563	918	8	11	-	32	
7	800	180	250	60	466	40	655	653	0	637	638	919	9	13	64	32	
7	800	180	250	120	466	80	797	790	1	792	791	956	8	13	62	37	
7	800	180	SKIP	SKIP	466	50				542	550	938	9	14	-	30	Compara
7	800	180	SKIP	SKIP	466	50				553	562	950	8	11	-	30	Compara
7	825	180	250	60	466	40	704	702	1	705	704	904	9	15	65	48	
7	825	180	250	120	466	80	773	760	1	763	763	895	8	13	62	63	
7	850	180	250	30	466	50	1031.	1031	0.0	940	1031	1074	4	6	-	58	
7	850	180	250	30	466	50	1041.	1040	0.1	951	1040	1076	3	5	-	58	
7	850	180	250	30	466	100	1003.	1000	0.0	926	1004	1053	4	6	-	64	
7	850	180	250	30	466	100	1035.	1030	0.7	940	1032	1067	5	6	-	64	
7	850	180	250	30	466	120	948.8	947.	0.1	904	948	1016	5	8	-	58	
7	850	180	250	30	466	120	953.3	953.	0.1	913	953	1019	5	6	-	58	
7	850	180	250	60	466	40	979	948	0	970	951	979	1	8	67	64	
7	850	180	250	120	466	80	1032	988	0	984	992	1032	1	9	65	58	
7	850	180	SKIP	SKIP	466	50				675	697	927	7	12	-	55	Compara
7	850	180	SKIP	SKIP	466	50				666	691	911	7	12	-	55	Compara

Table 11 Mechanical properties for alloy no. 8 of Table 3.

All oy No.	Tempera ture 1 (°C)	Time at Tempera ture 1 (s)	Tempera ture 2 (°C)	Time at Tempera ture 2 (s)	Tempera ture 3 (°C)	Time at Tempera ture 3 (s)	UY S(M Pa)	LYS (MP a)	YP E (%)	EU L Stre ss @ 0.5 %	0.2% OYS(M Pa)	UTS(M Pa)	Uniform Elongation (%)	TotalElong ation (%)	Hardn ess (HRA)	Hole Expans ion Ratio (%)	Note
8	800	180	250	30	466	50				731	750	978	8	12	-	35	
8	800	180	250	30	466	50				753	783	982	6	11	-	35	
8	800	180	250	30	466	100				739	762	970	6	9	-	42	
8	800	180	250	30	466	100				733	754	966	5	5	-	42	
8	800	180	250	30	466	120				557	554	970	8	10	-	37	
8	800	180	250	30	466	120				549	546	960	8	10	-	37	
8	800	180	250	60	466	40	766	764	1	767	773	960	8	12	64	39	
8	800	180	250	120	466	80	867	852	1	863	856	987	8	13	66	34	
8	800	180	SKIP	SKIP	466	50	1008.	1007	0.0	945	1008	1069	5	8	-	28	Compara
8	800	180	SKIP	SKIP	466	50				579	601	994	8	12	-	28	Compara
8	825	180	250	60	466	40	860	849	1	852	855	975	8	12	66	52	
8	825	180	250	120	466	80	875	854	1	872	852	931	7	11	63	62	
8	850	180	250	30	466	50	999.9	131.	0.0	930	1007	1048	3	5	-	58	
8	850	180	250	30	466	50				948	1024	1071	3	6	-	58	
8	850	180	250	30	466	100				937	1006	1063	3	6	-	49	
8	850	180	250	30	466	100				889	932	1005	5	8	-	49	
8	850	180	250	30	466	120				579	610	1003	7	11	-	69	
8	850	180	250	30	466	120				897	965	1034	4	6	-	69	
8	850	180	250	60	466	40	1090	1037	0	103	1048	1090	1	7	66	66	
8	850	180	250	120	466	80	1068	1022	0	100	1029	1068	1	9	64	89	
8	850	180	SKIP	SKIP	466	50				648	692	931	7	11	-	55	Compara
8	850	180	SKIP	SKIP	466	50				667	688	939	7	11	-	55	Compara

Table 12 Mechanical properties for alloy no. 9 of Table 3.

All oy No.	Temperat ure 1 (°C)	Time at Temperat ure 1 (s)	Temperat ure 2 (°C)	Time at Temperat ure 2 (s)	Temperat ure 3 (°C)	Time at Temperat ure 3 (s)	UY S(MP a)	LYS (MP a)	YP E (%)	EU L Stre ss @ 0.5 %	0.2% OYS(M Pa)	UTS(M Pa)	Uniform Elongation (%)	TotalElong ation (%)	Hardn ess (HRA)	Hole Expans ion Ratio (%)	Note
9	800	180	250	30	466	50				867	913	1040	6	9	-	-	
9	800	180	250	30	466	50				870	937	1042	6	9	-	-	
9	800	180	250	30	466	100				800	835	1001	7	10	-	-	
9	800	180	250	30	466	100				800	846	997	7	11	-	-	
9	800	180	250	30	466	120				847	884	1015	6	9	-	-	
9	800	180	250	30	466	120				879	911	1015	6	10	-	-	
9	800	180	250	60	466	40				890	923	998	6	9	65	58	
9	800	180	250	120	466	80				816	839	969	7	11	64	63	
9	800	180	SKIP	SKIP	466	50				543	543	958	9	15	-	-	Compara
9	825	180	250	60	466	40				968	998	1046	5	8	69	71	
9	825	180	250	120	466	80	1008	100	0	985	1003	1028	5	9	67	53	
9	850	180	250	30	466	50				870	932	1043	6	8	-	-	
9	850	180	250	30	466	50				863	913	1038	6	9	-	-	
9	850	180	250	30	466	100				894	936	1042	5	8	-	-	
9	850	180	250	30	466	100				882	923	1039	6	10	-	-	
9	850	180	250	30	466	120				758	817	1121	6	10	-	-	
9	850	180	250	30	466	120				844	887	1011	6	10	-	-	
9	850	180	250	30	466	120				537	542	955	9	14	-	-	
9	850	180	250	60	466	40				989	1006	1045	5	9	64	54	
9	850	180	250	120	466	80	1000	998	0	990	998	1040	5	9	64	71	

Table 13 Mechanical properties for alloy no. 10 of Table 3.

All oy No.	Temperat ure 1 (°C)	Time at Temperat ure 1 (s)	Temperat ure 2 (°C)	Time at Temperat ure 2 (s)	Temperat ure 3 (°C)	Time at Temperat ure 3 (s)	UY S(MP a)	LYS (MP a)	YP E (%)	EU L Stre ss @ 0.5 %	0.2% OYS(M Pa)	UTS(M Pa)	Uniform Elongation (%)	TotalElong ation (%)	Hardn ess (HRA)	Hole Expans ion Ratio (%)	Note
10	800	180	250	30	466	50				845	911	1150	6	9	-	-	
10	800	180	250	30	466	50				831	899	1148	6	9	-	-	
10	800	180	250	30	466	100				710	735	1137	7	10	-	-	
10	800	180	250	30	466	100				727	755	1132	7	10	-	-	
10	800	180	250	30	466	120				820	860	1147	7	10	-	-	
10	800	180	250	30	466	120				762	796	1138	7	9	-	-	
10	800	180	250	60	466	40	1019	101	1	974	1017	1139	7	11	68	34	
10	800	180	250	120	466	80	928	923	1	927	928	1132	8	12	68	43	
10	800	180	SKIP	SKIP	466	50				666	711	1158	6	11	-	-	Compara
10	800	180	SKIP	SKIP	466	50				648	684	1134	6	9	-	-	Compara
10	825	180	250	60	466	40	1089	107	1	101	1081	1149	6	11	68	41	
10	825	180	250	120	466	80	1077	106	1	101	1069	1125	6	10	69	41	
10	850	180	250	30	466	50				825	885	1125	6	9	-	-	
10	850	180	250	30	466	50				839	900	1126	6	9	-	-	
10	850	180	250	30	466	100				861	918	1129	6	9	-	-	
10	850	180	250	30	466	100				855	909	1118	6	9	-	-	
10	850	180	250	30	466	120				730	796	1130	6	9	-	-	
10	850	180	250	60	466	40				100	1057	1120	6	9	68	48	
10	850	180	250	120	466	80				993	1040	1113	6	9	65	49	

Table 14 Mechanical properties for alloy no. 11 of Table 3.

All oy No.	Tempera ture 1 (°C)	Time at Tempera ture 1 (s)	Tempera ture 2 (°C)	Time at Tempera ture 2 (s)	Tempera ture 3 (°C)	Time at Tempera ture 3 (s)	UY S(M Pa)	LYS (MP a)	YP E (%)	EU L Stre ss @ 0.5 %	0.2% OYS(M Pa)	UTS(M Pa)	Uniform Elongation (%)	TotalElong ation (%)	Hardn ess (HRA)	Hole Expans ion Ratio (%)	Note
11	800	180	250	30	466	50				692	706	1047	8	12	-	26	
11	800	180	250	30	466	50				667	676	1037	9	12	-	26	
11	800	180	250	30	466	100				719	751	1027	7	9	-	31	
11	800	180	250	30	466	100				714	738	1021	7	7	-	31	
11	800	180	250	30	466	120				608	611	1041	9	12	-	28	
11	800	180	250	30	466	120				621	623	1056	10	14	-	28	
11	800	180	250	60	466	40				727	731	1042	9	14	64	26	
11	800	180	250	120	466	80				769	776	1085	9	13	68	28	
11	800	180	SKIP	SKIP	466	50				590	599	1070	9	12	-	26	Compara
11	800	180	SKIP	SKIP	466	50				582	602	1060	9	12	-	26	Compara
11	825	180	250	60	466	40	778	768	1	775	777	1029	9	13	63	36	
11	825	180	250	120	466	80	820	807	1	820	809	995	9	15	61	36	
11	850	180	250	30	466	50	1094.	173.	0.0	940	1094	1132	6	8	-	40	
11	850	180	250	30	466	50				958	1112	1141	3	9	-	40	
11	850	180	250	30	466	100	1048.	1047	0.0	893	1048	1105	6	8	-	44	
11	850	180	250	30	466	100	1075.	151.	0.0	907	1071	1127	5	9	-	44	
11	850	180	250	30	466	120				907	1037	1114	6	9	-	45	
11	850	180	250	30	466	120				894	1011	1107	6	9	-	45	
11	850	180	250	60	466	40				104	1100	1162	1	5	67	42	
11	850	180	250	120	466	80				103	1072	1130	1	5	67	81	
11	850	180	SKIP	SKIP	466	50				668	720	1047	7	10	-	35	Compara
11	850	180	SKIP	SKIP	466	50				675	712	1046	7	11	-	35	Compara

Table 15 Mechanical properties for alloy no. 12 of Table 3.

All oy No.	Temperat ure 1 (°C)	Time at Temperat ure 1 (s)	Temperat ure 2 (°C)	Time at Temperat ure 2 (s)	Temperat ure 3 (°C)	Time at Temperat ure 3 (s)	UY S(MP a)	LYS (MP a)	YP E (%)	EU L Stre ss @ 0.5 %	0.2% OYS(M Pa)	UTS(M Pa)	Uniform Elongation (%)	TotalElong ation (%)	Hardn ess (HRA)	Hole Expans ion Ratio (%)	Note
12	800	180	250	30	466	50				650	687	1194	7	10	-	21	
12	800	180	250	30	466	50				660	698	1188	7	9	-	21	
12	800	180	250	30	466	100				770	815	1136	8	11	-	23	
12	800	180	250	30	466	100				897	924	1138	8	10	-	23	
12	800	180	250	30	466	120				641	693	1171	8	11	-	23	
12	800	180	250	30	466	120				656	710	1176	6	9	-	23	
12	800	180	250	60	466	40				811	819	1169	8	12	67	26	
12	800	180	250	120	466	80				760	766	1168	8	12	67	25	
12	800	180	SKIP	SKIP	466	50				661	720	1205	7	10	-	20	Compara
12	800	180	SKIP	SKIP	466	50				676	738	1225	7	10	-	20	Compara
12	825	180	250	60	466	40	849	846	1	852	856	1153	8	13	66	50	
12	825	180	250	120	466	80	1080	103	2	100	1038	1133	7	12	67	41	
12	850	180	250	30	466	50				913	1072	1196	7	10	-	30	
12	850	180	250	30	466	50				934	1102	1199	6	10	-	30	
12	850	180	250	30	466	100				912	1080	1192	7	9	-	32	
12	850	180	250	30	466	100				943	1109	1199	7	9	-	32	
12	850	180	250	30	466	120				837	954	1186	7	10	-	34	
12	850	180	250	30	466	120				829	956	1181	7	9	-	34	
12	850	180	250	60	466	40	1177	113	3	104	1141	1178	7	11	68	49	
12	850	180	250	120	466	80	1133	108	2	105	1098	1152	7	10	66	60	
12	850	180	SKIP	SKIP	466	50				727	831	1206	6	10	-	35	Compara
12	850	180	SKIP	SKIP	466	50				736	868	1230	6	10	-	35	Compara

[0042] It will be understood various modifications may be made to this invention without departing from the spirit and scope of it. Therefore, the limits of this invention should be determined from the appended claims.

What is claimed is:

1. A method for processing a dual phase steel sheet, the method comprising:
 - (a) heating the steel sheet to a first temperature (T1), wherein T1 is at least above the temperature at which the steel sheet transforms to austenite and ferrite to form at least some austenite in the steel sheet;
 - (b) cooling the steel sheet to a second temperature (T2) by cooling at a cooling rate, wherein T2 is below the martensite start temperature (M_s), wherein the cooling rate is sufficiently rapid to transform at least some the austenite to martensite;
 - (c) transitioning the steel sheet to a third temperature (T3); and
 - (e) cooling the steel sheet to room temperature.
2. The method of claim 1, further comprising hot dip galvanizing or galvannealing the steel sheet after the steel sheet is transitioned to T3.
3. The method of claim 1, wherein the hot dip galvanizing or galvannealing occurs above M_s .
4. The method of claim 1, wherein the step of cooling the steel sheet to T2 is performed prior to the step of transitioning the steel sheet to T3.
5. The method of claim 4, wherein the step of transitioning the steel sheet to T3 includes re-heating the steel sheet from T2 to T3.
6. The method of claim 1, wherein the step of cooling the steel sheet to T2 is performed after the step of transitioning the steel sheet to T3.
7. The method of claim 1, wherein the step of cooling the steel sheet to T2 is sufficiently rapid to transform substantially all austenite to martensite.
8. The method of claim 1, wherein the steel sheet comprises the following elements by weight percent:
0.080-0.1% carbon;

1.7-1.9% manganese;
0.15-0.25% silicon;
0.02% or less molybdenum;
0.015-0.025% niobium;
0.2-0.3% chromium; and
the balance being iron and other incidental impurities.

9. The method of claim 1, wherein the steel sheet comprises the following elements by weight percent:

0.067-0.080% carbon;
1.65-1.82% manganese;
0.15-0.25% silicon;
0.16-0.02% molybdenum;
0.001% or less niobium; and
the balance being iron and other incidental impurities.

10. The method of claim 1, wherein the steel sheet comprises the following elements by weight percent:

0.10-0.12% carbon;
2.1-2.3% manganese;
0.15-0.25% silicon;
0.003% or less niobium;
0.2-0.3% chromium; and
the balance being iron and other incidental impurities.

11. The method of claim 10, wherein the steel sheet further comprises 0.25-0.35% molybdenum.

12. The method of claim 1, wherein the steel sheet comprises the following elements by weight percent:

0.10-0.12% carbon;
1.75-1.9% manganese;

0.15-0.25% silicon;
0.035-0.045% niobium;
0.2-0.3% chromium; and
the balance being iron and other incidental impurities.

13. The method of claim 12, wherein the steel sheet further comprises 0.15-0.2% molybdenum.

14. The method of claim 1, wherein the steel sheet comprises the following elements by weight percent:

0.11-0.13% carbon;
2.4-2.7% manganese;
0.15-0.25% silicon;
0.35-0.45% molybdenum;
0.004% or less niobium;
0.3-0.4% chromium; and
the balance being iron and other incidental impurities.

15. The method of claim 1, wherein the steel sheet comprises the following elements by weight percent:

0.80-0.10% carbon;
2.0-2.2% manganese;
0.40-0.50% silicon;
0.04-0.060% niobium;
0.2-0.3% chromium; and
the balance being iron and other incidental impurities.

16. The method of claim 15, wherein the steel sheet further comprises 0.30-0.40% molybdenum.

17. The method of claim 1, wherein the steel sheet comprises the following elements by weight percent:

0.09-0.10% carbon;

2.25-2.42% manganese;
0.10-0.20% silicon;
0.035-0.045% niobium;
0.57-0.67% chromium; and
the balance being iron and other incidental impurities.

18. The method of claim 17, wherein the steel sheet further comprises 0.08-0.12% molybdenum.

19. The method of claim 1, wherein the steel sheet comprises the following elements by weight percent:

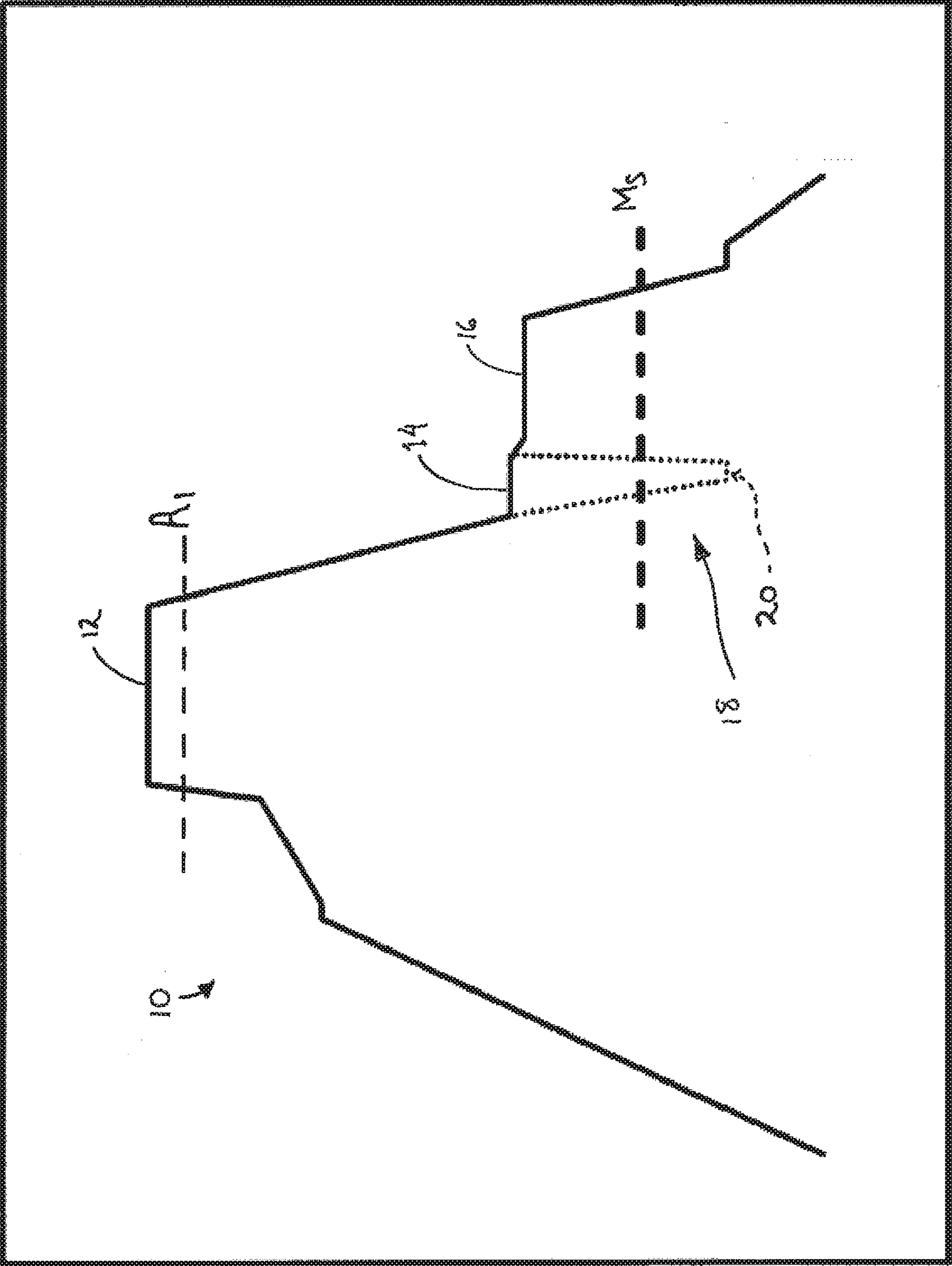
0.12-0.14% carbon;
2.7-2.9% manganese;
0.15-0.25% silicon;
0.004% or less niobium;
0.3-0.4% chromium; and
the balance being iron and other incidental impurities.

20. The method of claim 19, wherein the steel sheet further comprises 0.35-0.45% molybdenum.

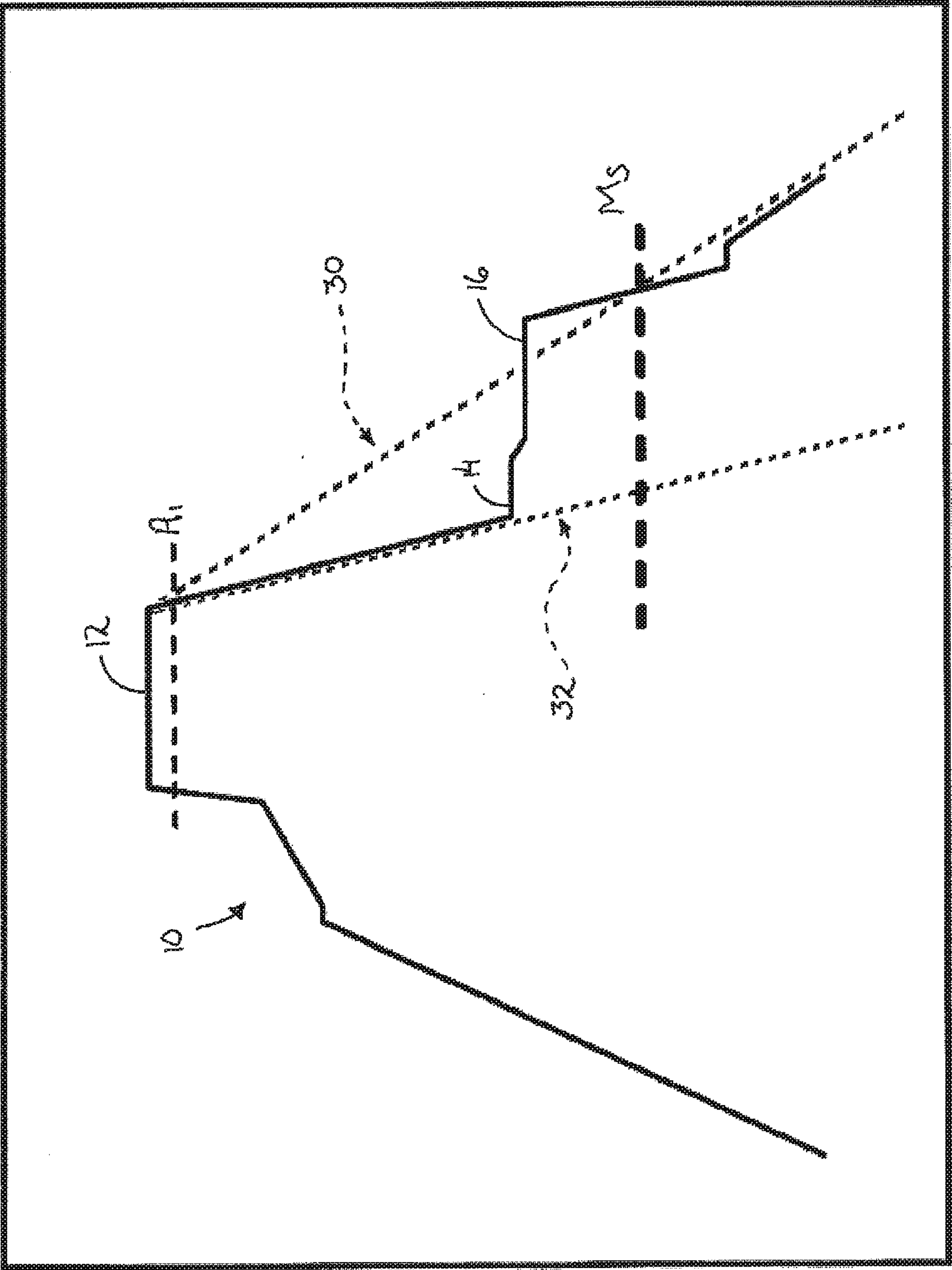
21. The method of claim 1, wherein the steel sheet comprises the following elements by weight percent:

0.11-0.13% carbon;
2.45-2.60% manganese;
0.420-0.580% silicon;
0.05% or less molybdenum;
0.035-0.045% niobium; and
the balance being iron and other incidental impurities.

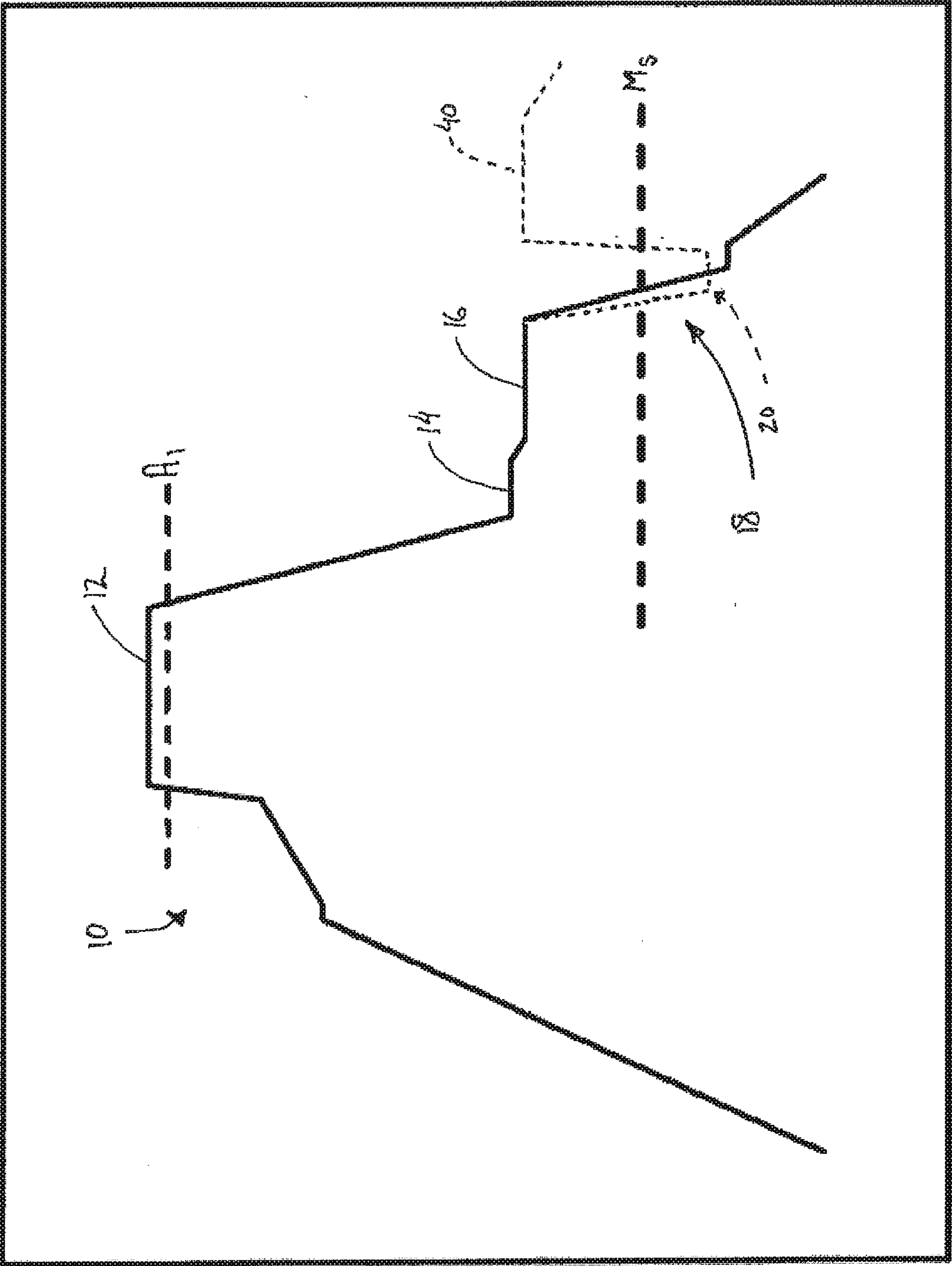
22. The method of claim 21, wherein the steel sheet further comprises 0.57-0.63% chromium.



Time
Fig 1



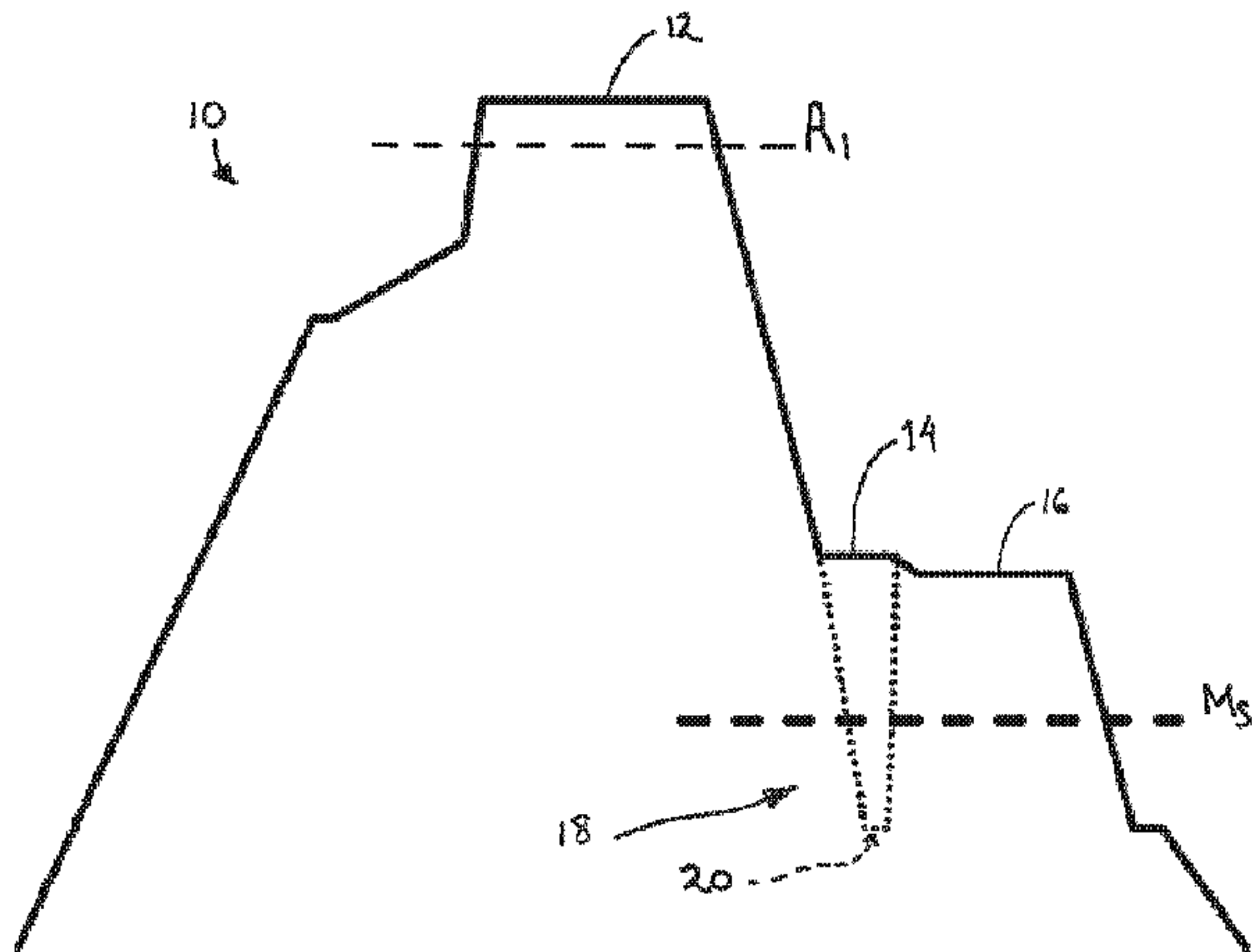
Time
Fig. 2



Time

Fig. 3

Temperature



Time

Fig 1