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(71) Applicant: KAWASAKI STEEL CORPORATION
1-28, Kitahonmachi-dori 1-Chome
Chuo-ku, Kobe-Shi Hyogo 651(JP)

(72) Inventor: Hashimoto, Hiroshi
7-3-A1007, Nitona-Cho
Chiba City(JP)

(72) Inventor: Takahashi, Isao
671-30, Minami-Iwasaki
Ichihara City(JP)

(72) Inventor: Kato, Toshiyuki
1351-E109, Sonnou-Cho
Chiba City(JP)

(72) Inventor: Shinozaki, Masatoshi
81-5, Shibuya
Mobara City(JP)

(72) Inventor: Irie, Toshio
3-6, Oguradai 2-Chome
Chiba City(JP)

(74) Representative: Overbury, Richard Douglas et al,
HASELTINE LAKE & CO Hazlitt House 28 Southampton
Buildings Chancery Lane
London WC2A 1AT(GB)

(54) A high strength hot rolled steel sheet having excellent flash butt weldability.

(57) A high strength hot rolled steel sheet having excellent flash butt weldability consisting of 0.04-0.15% of C, 0.5-2.3% of Mn, at most 0.5% of Si and 0.5-2.3% of Mn+Si, 0.05-0.15% of P, 0.005-0.100% of Aℓ and the remainder being Fe and incidental impurities and S content being reduced to at most 0.010%. The properties of such a steel sheet are improved by adding at least one of Ti, Nb and V or at least one of Ca and REM, or a combination of at least one of Ti, Nb and V with at least one of Ca and REM in the defined amounts.

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A HIGH STRENGTH HOT ROLLED STEEL SHEET HAVING EXCELLENT FLASH BUTT WELDABILITY

The present invention relates to high strength hot-rolled steel sheets for wheel rims, which have excellent flash butt weldability.

Recently, in the field of the automobile production, positive efforts have been made to reduce the weight of cars in order to decrease the fuel cost per running distance. As this means, it has been examined to use the high strength steel sheets instead of conventional mild steel sheets. Even in the wheel rims, the use of the high strength steel sheets has been studied but there have been remained a variety of problems.

The production of the wheel rim comprises the following steps. Strip-shaped thin steel sheets are generally cut off from a slit steel strip in a given dimension and formed into a loop form by roll bending. The butted end surfaces are flash-butt-welded to form a cylinder. The formed weld beads are removed and the cylinder was processed through a successive cold forming into a final shape and subjected to a test, whereby the formed articles are classified into the accepted ones and the defective ones. A problem usually taken into consideration in such a successive production step is the formabiliy of the flash-butt-welded portion in the cold forming line. In the cold forming of the wheel rim, the edges are subjected to an stretch flange forming and the elongation is as severe as 20-25%.

When it is attempted to use the high strength steel sheets for the wheel rim instead of the conventional mild steel sheets, the following problems occur.

1) The high strength steel sheets have high notch sensitivity at the sheared edges and the formability of the material itself is low.
2) The high strength steel sheets usually contain a larger amount of alloying elements, such as Si, Mn, etc. than the mild steel sheets, so that the hardness at the weld interface is increased by flash-butt-welding and the deterioration of formability the at the welds is high.

Heretofore, as the steel sheets for the wheel rim mild steel sheets, such as SAPH 32 of JIS G 3113 and the like have been used and the percent defective in the cold forming step is less than 1%, but when the high strength steel sheets are used as mentioned above, there are many problems and if the percent defective is taken into consideration, it is substantially impossible to apply the high strength steel sheets to the wheel rim.

The inventors have made a large number of investigations and found that (1) if the S content is reduced as far as possible or in addition to that an appropriate amount of Ca and REM is added, the stretch flangeability of the high strength steel sheets can be improved and (2) the deterioration of the formability of the welded joint can be prevented by intensionally adding P, the content of which has been restrained as low as possible because of fear of increase in the brittleness and even if the precipitation hardening elements, such as Nb, Ti or V are added, the properties are substantially maintained, and the inventors have succeeded to provide the high tensile strength hot rolled steel sheets which can be applied to the wheel rim, which has been heretofore considered to be impossible.

The development until attaining the present invention and the discovery will be explained in detail hereinafter.

The cold forming of the wheel rim is a process wherein the edges are subjected to stretch flanging forming. "Side bend test" is suitable for assessing this property accurately. The side bend test is carried out as follows. As shown in Fig. 1, a rectangular test piece 2 with sheared edges (width: 40 mm, length: 170 mm) is mounted on a test holder 1 and pressed down with a punch 3 in a direction perpendicular to the test piece and the pressing is continued until the test piece 2 is deformed and a crack A is formed as shown in Fig. 2, and the elongation d' (the distance of the marked points: 50 mm) at the curved outer surface is measured (the elongation obtained in this test is referred to as "side bend elongation").

The side bend elongation of so called mild steel sheet having a strength of lower than 40 kgf/mm^2, a conventionally produced solid solution hardened high strength steel sheet owing to C, Si or Mn and a precipitation hardened high strength steel sheet containing Nb, Ti or V were measured by using the above described test method and when the results were compared with the percent defective of the rim forming when the rim producing experiment was actually effected, it has been found that there is a high corelation between both the results as shown in Fig. 3 and that the side bend elongation of the welded joint must be more than 20% in order to obtain the percent defective of less than 1% which is the range where the wheel rim can be commercially manufactured. In Fig. 3, the open circle shows the mild steel sheet, the solid circle shows the high tensile strength steel sheets and only the mild steel sheet has the percent defective of rim forming being substantially near 0.

The inventors have continued the detailed study based on this discovery and found that the steel sheet obtained by adding an appropriate amount of P to high strength steel sheets containing a large amount of Si and Mn, is low in the deterioration of the formability at the welds in the flash butt welding. That is, when aluminum killed high strength hot rolled steel sheets consisting of

0.07-0.1% of C, 1.6-2.4% of Si+Mn, about 0.015% (not added) or about 0.08% (added) of P, 0.004-0.007% of S and the remainder being substantially Fe were flash butt welded and the side bend test of the welded joints was carried out, it has been found that as shown in Fig. 4, the side bend elongation of the rim formable range, that is the elongation of higher than 20% is shown only in the steels added with P. However, it is apparent from Fig. 4 that even in the steel added with P, when the content of Si+Mn exceeds 2.3%, the strength of the base material becomes too high, so that the side bend elongation of the welded joint suddenly lowers. Accordingly, it has been found that the addition of P is the essential requirement and Si+Mn must be at most 2.3%.

In order to examine the influence of the P content upon the side bend elongation of the welded joints, aluminum killed high strength hot rolled steel sheets consisting of 0.07-0.1% of C, about 1.9% of Si+Mn, 0.015-0.2% of P, 0.004-0.007% of S and the remainder being substantially Fe were flash butt welded and the side bend elongation of the welded joints was measured and it has been found that the side bend elongation wherein the rim forming is feasible, that is the elongation of higher than 20% is obtained by the P content of not less than 0.05%. The reason why the side bend elongation at the flash butt weld in the high strength steel sheet is considerably improved by the addition of P of not less than 0.05%, is not presently clear but is conceived as follows.

In general, the flash butt weld becomes the structure containing bainite or martensite with increase of Si+Mn and the hardness at this portion becomes higher but it has been found that when P is added to the steel having such a structure, ferrite increases at the weld and the ferrite grains at the heat affected zone are apt to become larger. Accordingly, the difference of the hardness between the base metal and the weld presumably becomes small in the P added steel and the formability of the flash butt weld is improved.

The present invention has been attained based on the above described discovery and lies in a high strength hot rolled steel sheet having excellent flash butt weldability which consists of 0.04-0.15% of C, 0.5-2.3% of Mn, at most 0.5% of Si and 0.5-2.3% of Mn+Si, 0.05-0.15% of P, 0.005-0.100% of Aℓ and the remainder being Fe and incidental impurities and in which the S content is reduced to less than 0.010%.

The above described composition is made to be the fundamental components and when the higher strength is required, at least one of Ti, Nb and V which are the precipitation hardening elements is added to said composition in a total amount of 0.01-0.1%.

When the formability is intended to be improved, at least one of Ca and REM which are the sulfide forming elements, is added to the above described composition in a total amount of 0.001-0.005%.

Furthermore, in a preferred embodiment, both the above described precipitation hardening elements and sulfide forming elements are added.

For a better understanding of the invention, reference is taken to the accompanying drawings, wherein:

Fig. 1 is a diagrammatic view showing cross-section of a side bend test jig;

Fig. 2 is a vertical view showing the form of a test piece after applying to the side bend test;

Fig. 3 is a graph showing the relation between the side bend elongation and the percent defective of the rim forming;

Fig. 4 is a graph showing the relation between the side bend elongation of the flash butt welded joints and the contents of Si+Mn and P; and

Fig. 5 is a graph showing the relation between the side bend elongation of the flash butt welded joints and the P content.

Explanation will be made with respect to the reason for limiting the fundamental component composition of the first aspect of the present invention.

C needs at least 0.04% for ensuring the strength, while when the C content exceeds 0.15%, the deterioration of the formability becomes higher, so that the C content is limited within the range of 0.04-0.15%.

Mn needs at least 0.5% for obtaining the high tensile strength but when said content exceeds 2.3%, the formability is considerably deteriorated, so that the Mn content is limited within the range of 0.5-2.3%.

Si is an active element for increasing the tensile strength but when the Si content exceeds 0.5%, the phosphate treating ability which is a pretreatment upon coating, is deteriorated, so that the addition of Si is at most 0.5%.

When Mn+Si exceeds 2.3%, the side bend elongation of the welded joint is lower than 20%, so that the upper limit is 2.3% and the lower limit is defined to be 0.5% which is necessary for obtaining the high tensile strength.

As shown in Fig. 5, unless the P content is not less than 0.05%, the side bend elongation of more than 20% can not be obtained but if said content exceeds 0.15%, the effect is maintained but the brittleness becomes noticeable, so that the upper limit is 0.15%.

Aℓ is an element used for the deoxidation but when said content is less than 0.005%, the deoxidation is insufficient and the formability is deteriorated owing to the oxide inclusions. On the other hand, when the Aℓ content exceeds 0.10%, alumina inclusions increase and the surface state is deteriorated and further the formability is deteriorated, so that the Aℓ content is limited to the range of 0.005-0.10%.

S is preferred to be low as far as possible. In the high strength steel sheet, the notch sensitivity of the sheared edge is high and the deterioration of the formability is higher, so that it is necessary to reduce the sulfide inclusions as far as possible. For the purpose, S must be at most 0.01%.

Explanation will be made with respect to the second aspect of the present invention, which is the high strength hot rolled steel sheet having excellent flash butt weldability in which 0.01-0.1% of at least one of Ti, Nb and V is added in the total amount to the composition of the first aspect of the present invention.

In general, when the high strength steel sheet is produced, a solid solution hardening element, such as C, Mn or Si is selected as the component but when the high strength steel sheet having the higher strength is produced, it is usual to add a precipitation hardening element, such as Nb, Ti or V together with these solid solution hardening elements, when the inventors have examined the effect for improving the side bend elongation due to the addition of P based on the above described already obtained knowledge, by adding at least one of the above described precipitation hardening elements to the composition of the first aspect of the present invention containing 0.05-0.15% of P, it has been found that the steel containing 0.01-0.1% of at least one of Ti, Nb and V in the total amount can improve the tensile strength without deteriorating the effect for improving the side bend elongation owing to the addition of P.

The reason why the total amount of at least one of Ti, Nb and V is limited within the range of 0.01-0.1% is as follows. When the content is less than 0.01%, it is difficult to obtain the high strength and when the content exceeds 0.1%, the improvement of the strength does not increase in proportion to the increase in the addition amount.

Explanation will be made with respect to the third aspect of the present invention, which is the high strength hot rolled steel sheet having excellent flash butt weldability characterized in that 0.001-0.05% of at least one of Ca and REM is contained in the total amount in addition to the composition of the first aspect of the present invention.

As mentioned in the reason of limitation of S in the first aspect of the present invention, the smaller the amount of sulfides in the high strength steel sheets, the higher the formability of the steel is. However, it has been known that even in the same amount of sulfides, there is difference in the formability depending upon the state of the sulfide in the steel and when the sulfide is present as MnS, said sulfide is generally in the elongated state in the rolling direction, so that the formability in the direction pependicular to the rolling direction is poor and that in order to improve this defect, it is effective to add Ca or REM to make the sulfide into small globular forms.

When the inventors have examined the effect for improving the side bend elongation due to the addition of P based on the above described already obtained knowledge, by adding at least one of the above described elements Ca and REM to the composition of the first aspect of the present invention containing 0.05-0.15% of P, it has been found that the steel containing 0.001-0.05% of at least one of Ca and REM in the total amount can improve the side bend elongation of the welded joint and the side bend elongation of the base metal.

The reason why the amount of at least one of Ca and REM is limited within the range of 0.001-0.05% is as follows. Ca or REM combines with S to make the inclusion globular, whereby the formability is improved, so that these elements are added in an amount of not less than 0.001% alone or in combination. While the addition of more than 0.05% does not increase the effect and oxide inclusions are formed and the formability is rather deteriorated, so that the amount is at most 0.05%.

Explanation will be made with respect to the fourth aspect of the present invention, which is the high strength hot rolled steel sheet having excellent flash butt weldability characterized in that the total amount of 0.01-0.1% of at least one of Ti, Nb and V and the total amount of at least one of Ca and REM are concurrently contained in addition to the composition of the first aspect of the present invention.

Experiments have been made in the same manner as mentioned in the second and third aspects of the present invention and it has been found that the steels of the fourth aspect of the invention have the effect for improving the side bend elongation due to the addition of P and the more improved strength is obtained and the side bend elongation of the base metal is improved.

In general, when the content of Mn and Si is increased, the oxides of Si and Mn remain in the weld interface and may cause weld defects. When Mn/Si ratio is 4-12, the melting point of the oxides formed in the welding is lowered and therefore said oxides are readily removed when upsetting upon the welding and the properties of the weld are improved.

The steels of the present invention can be produced through the prior technic by means of the usually used installation and the production will be explained in summary.

Steels refined in a usual refining furnace, such as a converter are cast through a slab making process or a continuous casting process. In this case, it is necessary to make the S content to be less than 0.010%, so that it is preferable that the S content has been made to be low after the iron melting step. The steel ingot or the continuously cast slab is formed through the usual hot rolling installation and technic into a hot coil and the thickness of the sheet is in many cases 2-4mm.

The following examples are given for the purpose of illustration of this invention and are not intended as limitations thereof.

Steels having 12 kinds of chemical compositions as shown in Table 1a were refined in a converter and continuously cast. The cast steel slabs were reheated at a temperature of 1,250-1,300°C and hot rolled at a finishing temperature of 850°C±20°C and a coiling temperature of 580°C±20°C and passed through a general pickling line or a shot line to obtain a hot rolled steel sheet having a thickness of about 2.6 mm, and the obtained steel sheets were tested with respect to the properties as shown in Table 1b. "Percent defective of the wheel rim forming" shown in the following Table 1b was determined by carrying out the production test in the rim forming line by using the above described steel sheets.

Table 1a

Sample No.	Steel	Chemical composition (%)												
		C	Si	Mn	P	S	Aℓ	Nb	Ti	V	Ca	REM	Si+Mn	Mn/Si
A	Present invention	0.081	0.30	1.15	0.095	0.003	0.031	-	-	-	-	-	1.45	3.8
B	"	0.067	0.21	1.53	0.088	0.006	0.046	0.042	-	-	-	-	1.74	7.3
C	"	0.082	0.21	1.54	0.136	0.005	0.043	-	0.035	-	-	-	1.75	7.3
D	"	0.076	0.25	1.70	0.087	0.005	0.041	-	-	0.065	-	-	1.95	6.8
E	"	0.084	0.05	1.07	0.063	0.004	0.040	0.010	0.052	-	-	-	1.12	21.4
F	"	0.069	0.14	1.55	0.088	0.006	0.046	-	-	-	-	0.007	1.69	11.1
G	"	0.075	0.19	1.52	0.090	0.004	0.037	0.041	-	-	0.012	0.008	1.71	8.0
H	"	0.083	0.13	1.61	0.082	0.005	0.045	0.039	-	-	-	-	1.77	12.4
I	Comparative steel	0.071	0.43	1.56	0.015	0.007	0.044	-	-	-	-	-	1.99	3.6
J	"	0.084	0.27	0.89	0.183	0.006	0.058	-	-	-	-	-	1.16	3.3
K	"	0.071	0.30	2.18	0.081	0.004	0.052	-	-	-	-	-	2.48	7.0
L	"	0.081	0.21	1.53	0.086	0.012	0.047	0.045	-	-	-	-	1.74	7.3

Table 1b

Sample No.	Properties of steel sheets		Properties of the welded joint	Percent defective of the wheel rim forming (%)
	Tensile strength (kgf/mm^2)	Side bend elongation (%)	Side bend elongation (%)	
A	52.7	38	35	0.5
B	61.2	30	27	0.9
C	62.8	28	26	0.9
D	60.6	28	27	0.9
E	64.8	29	28	0.8
F	62.8	33	29	0.8
G	61.4	34	30	0.7
H	60.8	32	28	0.8
I	50.4	37	19	12.0
J	59.3	30	25	0.9
K	57.4	25	11	50.0
L	61.6	21	18	21.2

As seen from Table 1b, aluminum killed high strength hot rolled steel sheets (A-H) of the present invention containing the defined amounts of C, Si, Mn, P and S are low in the deterioration of the side bend elongation of the flash butt welded joints and the lowering ratio is 2-4% and the side bend elongation shows the value of higher than 20%, wherein the wheel rim forming is feasible.

In the steel I which is a comparative steel, since the P content is as low as 0.015%, the side bend elongating percent of the base metal is high but that of the welded joint is as low as 19%. In the steel J, since the P content is as high as 0.183%, the bend side elongating percent of the welded joint is as high as 25% but the brittleness is noticeable, so that this amount is excluded from the present invention. In the steel K, Si+Mn are as high as 2.48%, so that the side bend elongation of the welded joint is as low as 11%. In the steel L, the S content is as high as 0.012%, so that the side bend elongation of the base metal is low and the side bend elongation of the welded joint is as low as 18%.

As mentioned above, the steels of the present invention are low in the deterioration of the side bend elongation of the flash butt weld and develop the excellent quality properties and the application of the high strength hot rolled steel sheets to the wheel rim has become easy, which has been considered to be inflasible. Thus, the present invention can contribute to the reduction in the fuel cost per running distance due to the decrease in the car weight.

The present invention can apply to the materials to be worked after the flash butt welding as well as to a wheel rim.

CLAIMS

1. A high strength hot rolled steel sheet having excellent flash butt weldability consisting of 0.04-0.15% of C, 0.5-2.3% of Mn, at most 0.5% of Si and 0.5-2.3% of Mn+Si, 0.05-0.15% of P, 0.005-0.100% of Aℓ and the remainder being Fe and incidental impurities and S content being reduced to at most 0.010%.

2. A high strength hot rolled steel sheet having excellent flash butt weldability as claimed in claim 1, wherein at least one of Ti, Nb and V is additionally added in a total amount of 0.01-0.1%.

3. A high strength hot rolled steel sheet having excellent flash butt weldability as claimed in claim 1, wherein at least one of Ca and REM is additionally added in a total amount of 0.001-0.05%.

4. A high strength hot rolled steel sheet having excellent flash butt weldability as claimed in claim 1, wherein at least one of Ti, Nb and V in the total amount of 0.01-0.1% and at least one of Ca and REM in the total amount of 0.001-0.05% are additionally added.

5. A high strength hot rolled steel sheet having excellent flash butt weldability as claimed in claim 1, wherein Mn/Si is 4-12.

FIG_1

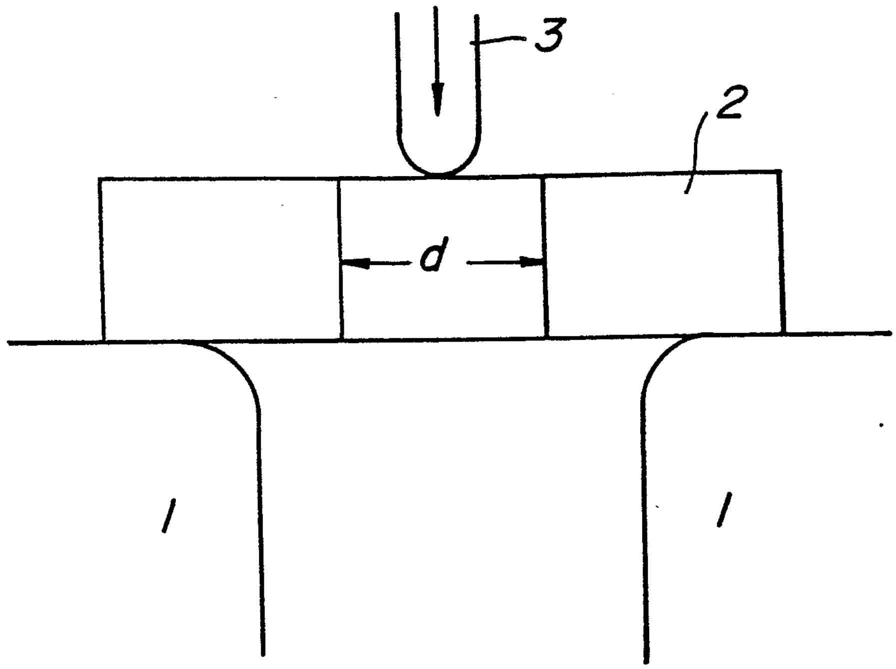


FIG_2

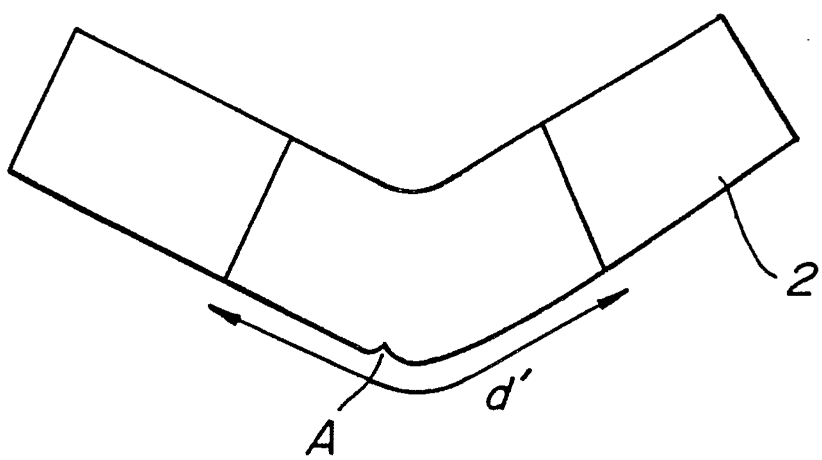
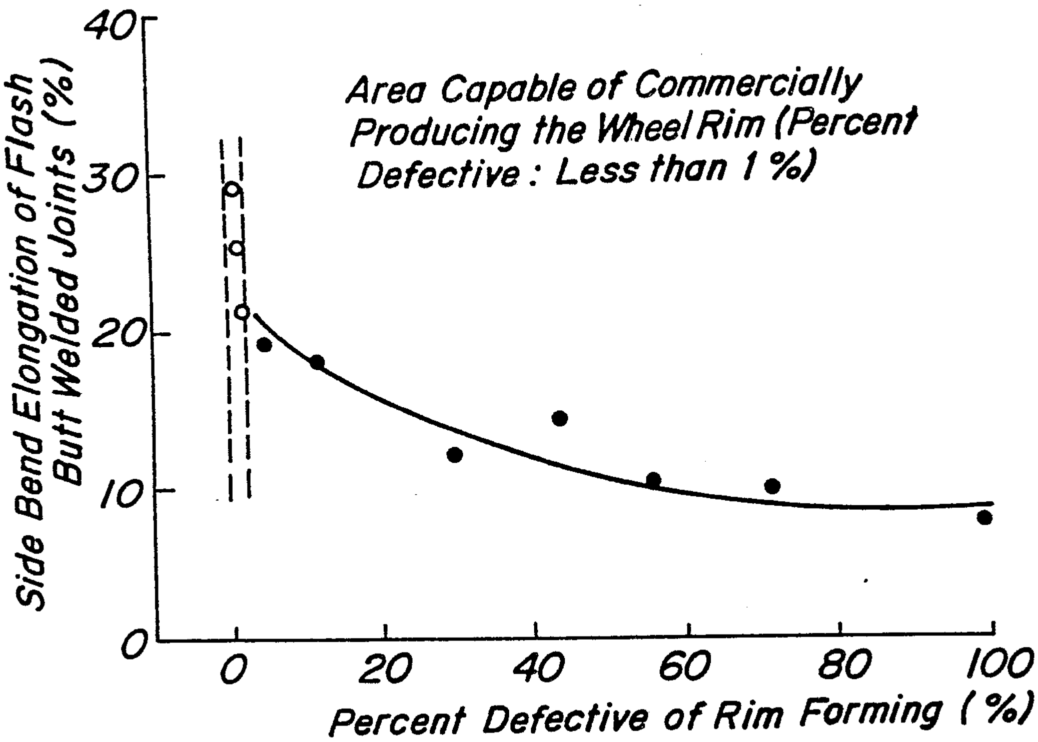
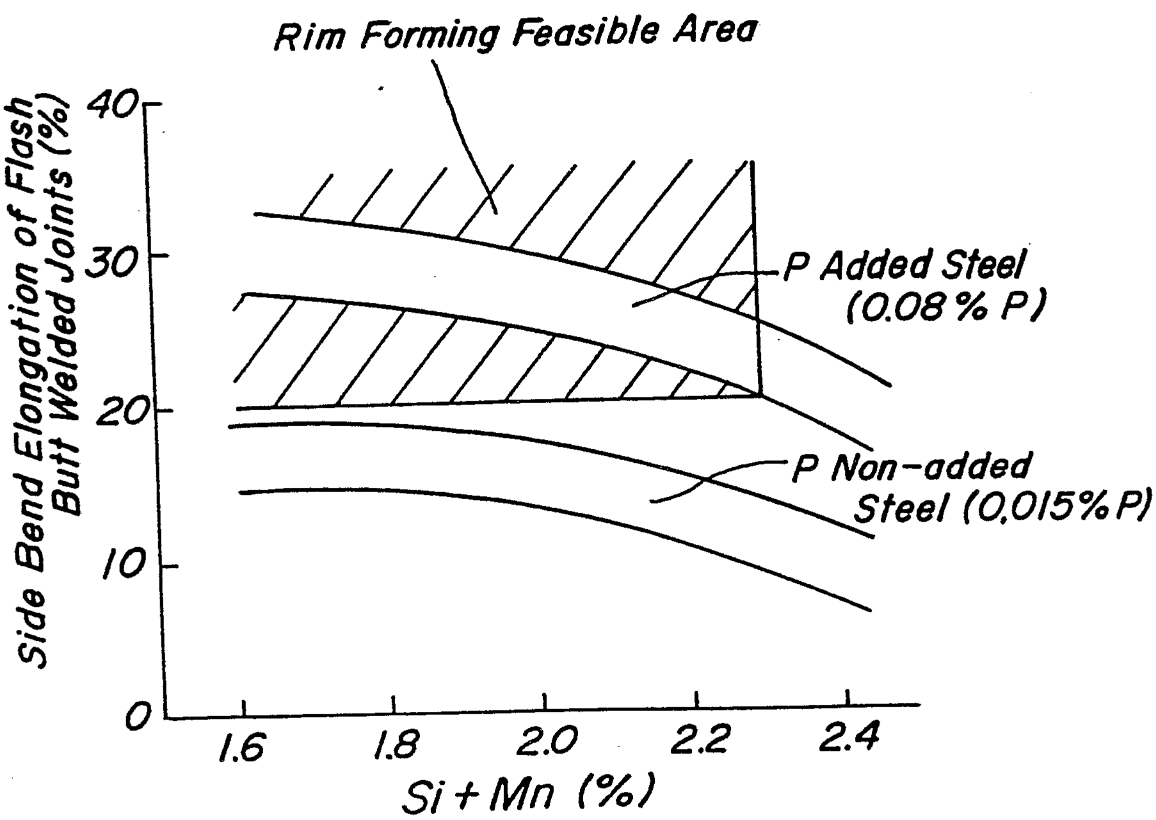


FIG.3



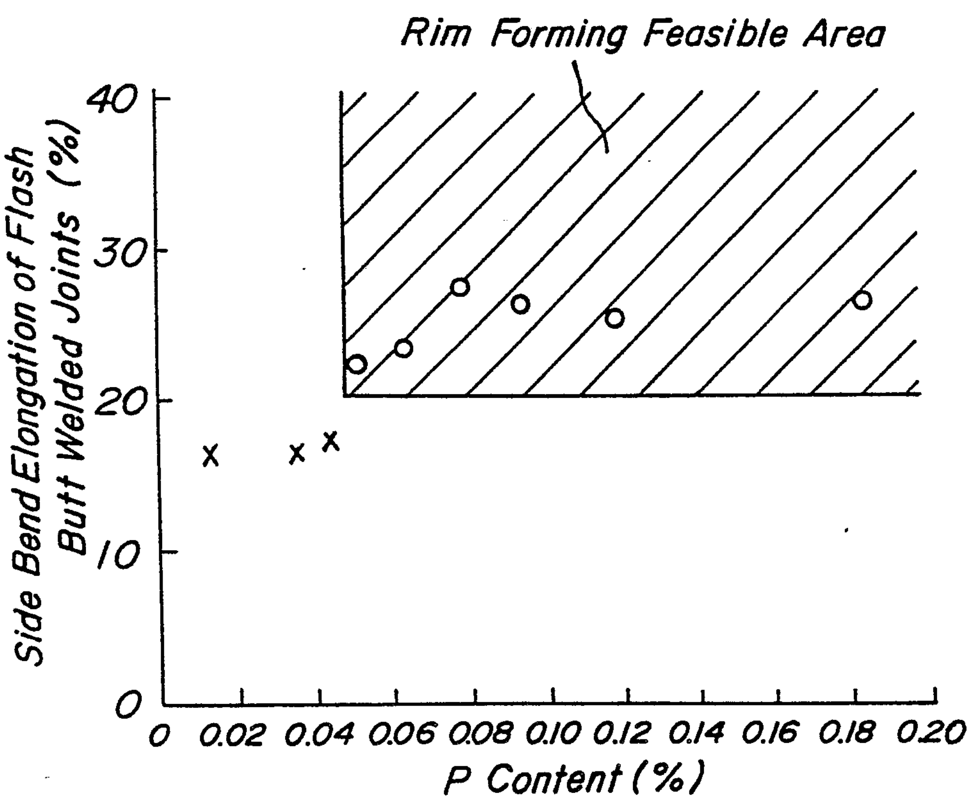
Side Bend Elongation of Flash Butt Welded Joints (%)
40
30
20
10
0
Area Capable of Commercially Producing the Wheel Rim (Percent Defective : Less than 1 %)
0
20
40
60
80
100
Percent Defective of Rim Forming (%)

FIG.4



Rim Forming Feasible Area
Side Bend Elongation of Flash Butt Welded Joints (%)
40
30
20
10
0
P Added Steel (0.08 % P)
P Non-added Steel (0.015% P)
1.6
1.8
2.0
2.2
2.4
Si + Mn (%)

FIG_5


Rim Forming Feasible Area
Side Bend Elongation of Flash Butt Welded Joints (%)
40
30
20
10
0
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
P Content (%)