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A NEW HSLA STEEL FOR AN AUTOMOTIVE STEERING COUPLING COMPONENT

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A SPECIAL PROCESSED STEEL was developed and has been used successfully to manufacture more than 45 million parts. Design objectives were low weight and 552MPa (80ksi) minimum yield. Processing required ultra good formability with no cracking and a high degree of dimensional stability. A special heat treatment on a HSLA provided excellent formability with the capability of exceeding 552MPa (80ksi) after straining and low temperature thermal aging. It is a dual-phased, micro-alloyed steel identified as GM980X.

This paper describes the development and the production experience since 1976. Data is shown on over 7 million pounds of steel involving 73 heats. The steel is cost effective in comparison with a conventional heat treated steel.

1. Specifications require 552MPa (80ksi) min. yield after 5% strain and 163°C. (325°F.) age.
2. Tensile tests are performed on each heat in both the as-received condition and after strain and thermal aging.
3. Control procedures require testing of both ends of each master coil.
4. This part can always be formed successfully when the elongation exceeds 26%.
5. The cause of low elongation and forming cracks can be identified as microstructural variations by standard metallographic techniques.

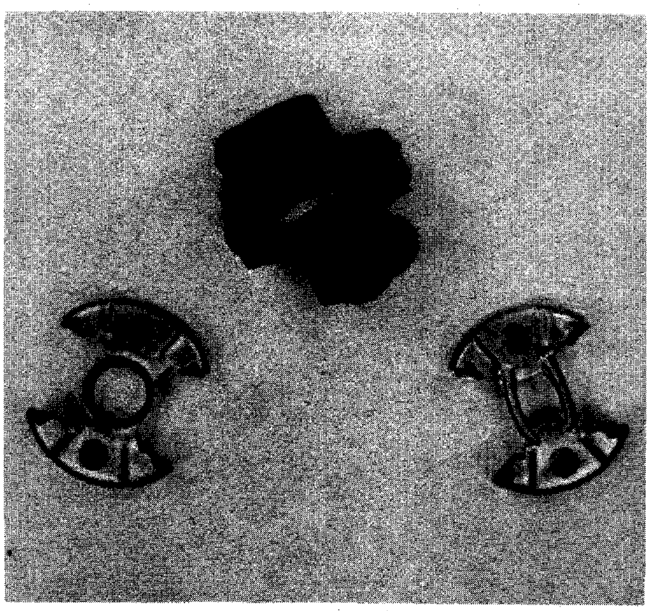


FIG. 1 STEERING REINFORCEMENT ASSEMBLY

A new small steering shaft coupling was designed and developed for a new small car for the 1975 model year. Important components in the success of this design were the coupling reinforcements shown in Fig. 1. The coupling transmits the torque required to steer the vehicle. The reinforcements are the torque carrying members of the coupling when steering torques exceed the capacity of the rubber element.

A program was initiated to provide a small coupling and intergal stone shield for 1976 power steered vehicles which could also be used in future manual steered models. The current coupling O.D. was 86mm compared to the small coupling O.D. of 68mm. To allow space for the stone shield it was desireable to adopt the existing 68mm O.D. coupling design.

The SAE1008 material used for the reinforcement had been selected for its excellent formability. To meet the strength requirements of the larger vehicle applications the parts were carburized, quenched, and highly tempered. This provided sufficient strength but due to the thin section and internal stress induced by the forming operations severe distortion problems were encountered in production. Initially only a few hundred parts a day were required but additional production volumes of several thousand per day were scheduled. A process or material was needed which would eliminate the heat treat distortion and provide the required strength. Extensive studies of various heat treatments and methods of fixturing parts were conducted to reduce the heat treat distortion to acceptable levels.

Replacing the SAE1008 material with SAE1017MOD (.60/.90 Mn) to improve the uniformity of the hardening in the carburizing heat treatment did not significantly reduce distortion but did eliminate the soft spots which were present in the SAE1008 parts after quenching. A study of the orientation of the part with respect to the grain direction of the coil steel did not show a significant reduction in distortion. Carbon diffusion and austempering heat treatment looked promising but required a large capital investment and long lead times.

High strength low alloy steels were tried but the available materials with 483-550MPa yield strength would not make the part. Discussion with Dr. M. S. Rashid of General Motors Research Metallurgical Department on a new HSLA steel he had developed, called GM980X, started an investigation of this material. With its low yield strength, lack of yield point elongation and improved total elongation compared to other HSLA materials, the GM980X looked as if it would provide the formability required to make the reinforcements. (Fig. 2) The yield strength increase during forming and the strain aging treatment to 550MPa from the initial yield strength of 400MPa was important to obtain the yield strength required.

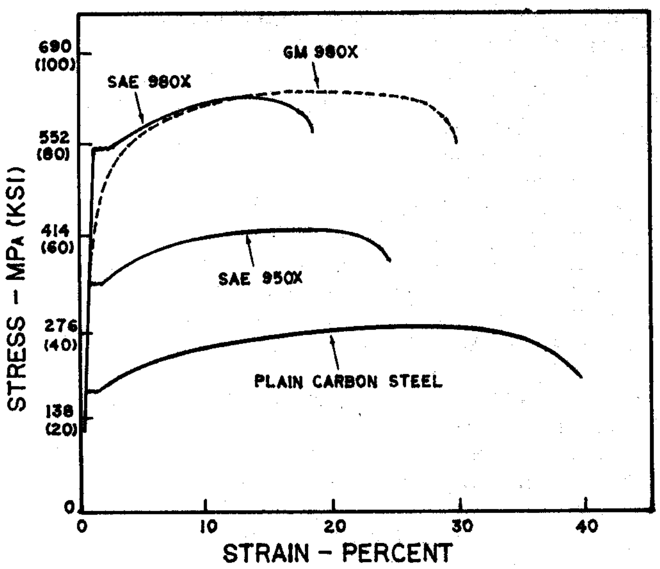


FIG. 2 GM980X EXHIBITS 10% HIGHER TOTAL ELONGATION THAN SAE980X. ALSO NOTE THE GM980X HAS NO YIELD POINT ELONGATION. (1)

Material samples were supplied by Dr. Rashid at the 1.5mm thickness currently in production. The blanks were hand transfered through current production progressive dies, forming the parts without any problems. The parts were then Zinc plated and strain aged at 160°C. for four hours. This cycle was currently used to stress relieve the parts after the Zinc plating operation.

The reinforcements were assembled and submitted for fatigue and wear tests. The fatigue test consists of a reversing torsional load input into the upper shaft with a restraining load on the lower shaft and an angle of 3 to 5° between the axes of the shafts. The load is applied at a rate of 90 cycles per minute with a cycle consisting of applying the reversing torsional load once in each direction. A manual steering assembly must withstand 2000 cycles at 55N·m and 18000 cycles at 27N·m with a 3° angle between axes of the steering shafts. A power steering assembly must withstand 1000 cycles at 55N·m and 19000 cycles at 27N·m with a 5° angle.

The wear test consists of three revolutions in each direction at 60rpm for each cycle of the test. Power steering applications require a 5° angle between the upper and lower steering shafts and completion of 20,000 test cycles with a 6.8N·m restraining load. Manual steering applications require a 3° angle between the steering shafts and a 20.4N·m restraining load for 20,000 cycles.

The GM980X parts met the test requirements.

Data obtained on the increase in yield strength (ΔY) during strain aging showed a greater ΔY, during strain aging at 160°C., with a 1.6% pre-strain than with 10% pre-strain. There is little effect on ΔY between 1 and 4 hours strain aging time at 160°C. at these levels of pre-strain. (Fig. 3) We will cover the effects of strain aging on this material in more detail later in the article.

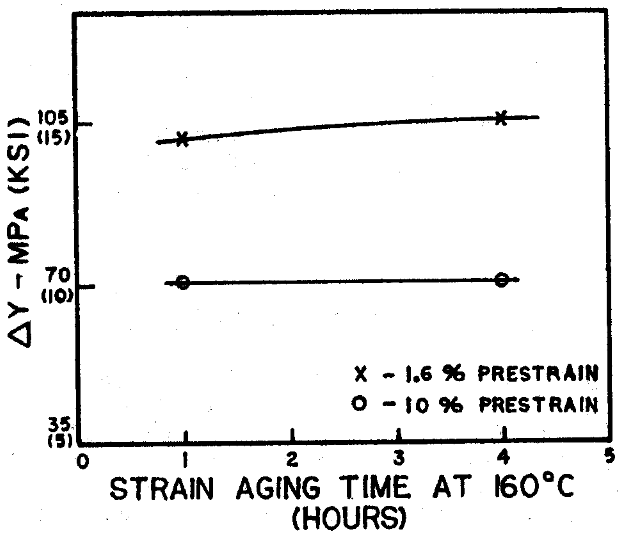


FIG. 3 Yield Strength Increase, ΔY, from 160°C. Strain Aging at Different Levels of Prestrain (2)

At this point we had a material which would meet design requirements but there was not a production source for GM980X with 1.5mm thickness. Working with Dr. Rashid we set up a meeting with Jones and Laughlin Steel to discuss production quantity availability, as the 980X material we were using was based on their VAN80 HSLA steel. They agreed to supply production material.

INTRODUCTION TO PRODUCTION

As previously reported, the design objectives for these steering reinforcements could be met with a conventional low carbon steel by using a surface hardening process for added strength. A major problem existed with this method which was distortion caused by the heat treating process. The flatness near the bolt holes varied, depending on the type of heat treatment used. (Fig. 4) The thin, non-uniform sections made heat treat very difficult. This distortion caused assembly line rejects, scrap, and reworks and was the major reason for looking at alternate steels and processes.

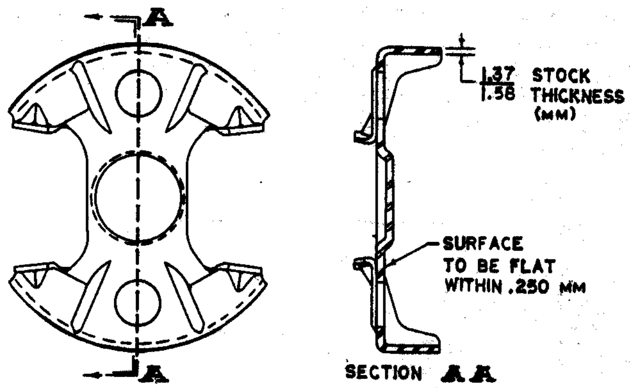


FIG. 4 CRITICAL AREA OF DISTORTION

The specification required a maximum distortion in flatness of .250mm. Our best heat treatment produced a mean distortion of .152 and a maximum of .406, which greatly exceeded the specification. (Fig. 5) GM980X could be used with a 163°C. strain aging treatment and showed a mean distortion of .086 and a maximum of .130mm, which has not caused any assembly problems. This basic fact has held true through seven years of production and the manufacture of more than 45 million parts.

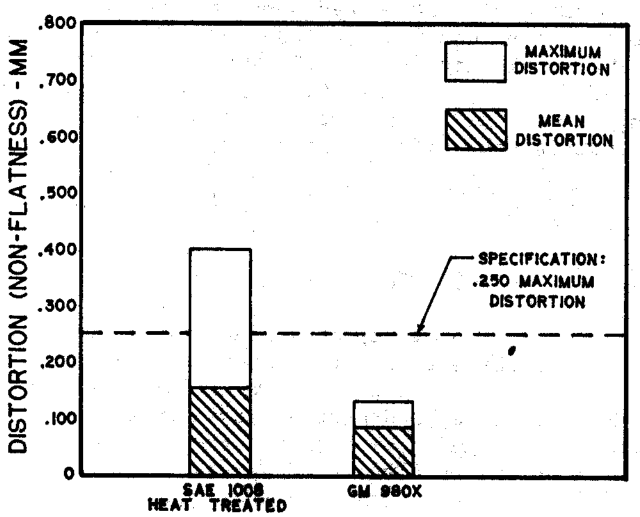


FIG. 5 COMPARISON OF DISTORTION RESULTING FROM DIFFERENT PROCESS

When considering the total costs of using SAE1008 steel with its added heat treat operation and assembly problems of scrap and rework, GM980A shows a significant cost savings, despite its approximately 25% initial cost penalty. An overall productivity improvement has been accomplished by its use.

One of the reasons GM980X has been successful for this application is that it solved a problem instead of creating problems which other high strength materials have caused in some applications. Other HSLA steels do not have sufficient formability for these reinforcements and have not been seriously considered. Manufacturing supervision and engineers were concerned about the wear and maintenance of the tooling as well as the formability. Actually, very slight die modifications were necessary for converting from SAE1008 to GM980X and there has been no problems. Again, manufacturing people were receptive to the extra efforts required to make it work because it solved a problem.

SUMMARIES

The procedures that have been found necessary to make the program successful are summarized as follows:

1. The part requires that the steel have the capability of attaining a yield strength of 552MPa after a 5% strain and 163°C. age. This test is performed by cutting a standard tensile strip, straining 5%, aging at 163°C. and completing the tensile test on the same specimen.
2. Tensile tests are performed on samples from each heat in both the "as-received" condition and after straining and thermal aging.
3. Control procedures require tensile testing of both ends of each master coil.
4. Experience has shown this part can be formed successfully when the elongation exceeds 26%.
5. The cause of low tensile and elongation values as well as forming cracks has been identified as microstructural variations by standard metallographic techniques.

VALIDATION OF PRODUCTION PROCESS

During the validation of the production processing methods, it was necessary to develop a thorough understanding of the properties of GM980X material. The following data was developed on one of the first heats of material that was used for production.

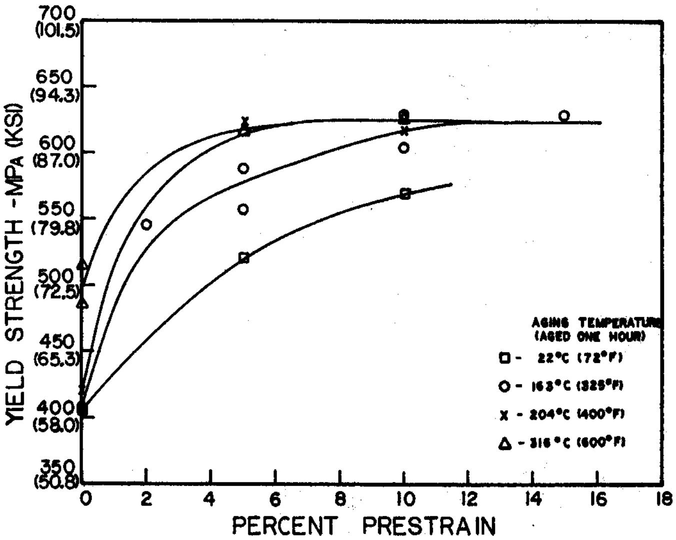


FIG. 6 YIELD VS. PRESTRAIN AT VARIOUS AGING TEMP

Fig. 6 shows how the yield strength varies with different amounts of pre-strain--and at four different aging temperatures. You will note that with zero pre-strain, aging has little effect, but small amounts of pre-strain cause rapid increases in yield strength when it is followed by an aging process. Yield strength approaches maximum by pre-straining at 10% and thermal aging at 163°C. Maximum yield can be reached with less pre-strain (5%) and using a higher aging temperature of 288°C. No significant increase in yield strength can be gained by straining more than 10%.

Fig. 7 shows how the yield strength varies with aging temperature after pre-straining at three different levels. With zero pre-strain, the yield does not increase appreciably until a temperature of 288°C. is used. The highest yield strength that an be reached with zero pre-strain is 475MPa using an aging temperature of 750°C. Again, maximum yield can be reached with 10% pre-strain and 288°C. aging.

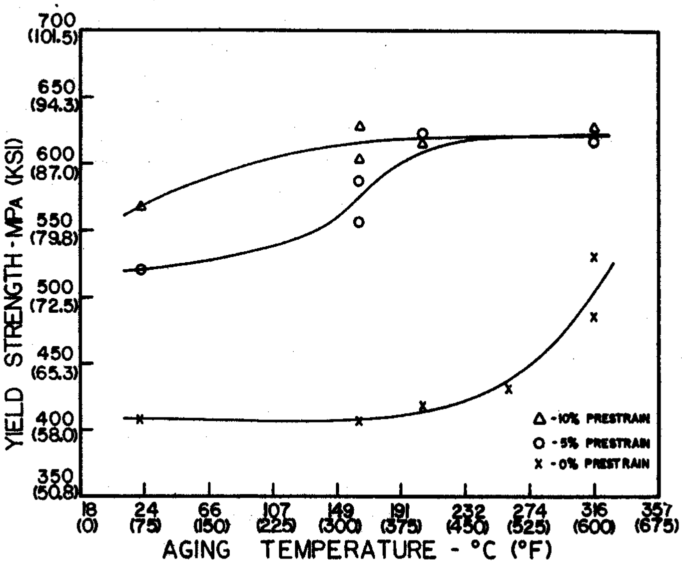


FIG. 7 YIELD VS. AGING TEMP AT VARIOUS PRESTRAINS

For our steering reinforcements, the amount of strain developed in the forming process varies considerably in different areas. While we were prepared to introduce additional strain in selected areas, we learned from product testing that the areas of critical strength requirements received sufficient pre-strain to respond adequately to various aging treatments. A basic process consisting of 163°C. for one hour was determined to satisfactorily meet all design objectives and this has been used successfully for seven years. It is the same process that had been in effect as a stress relief after Zinc plating.

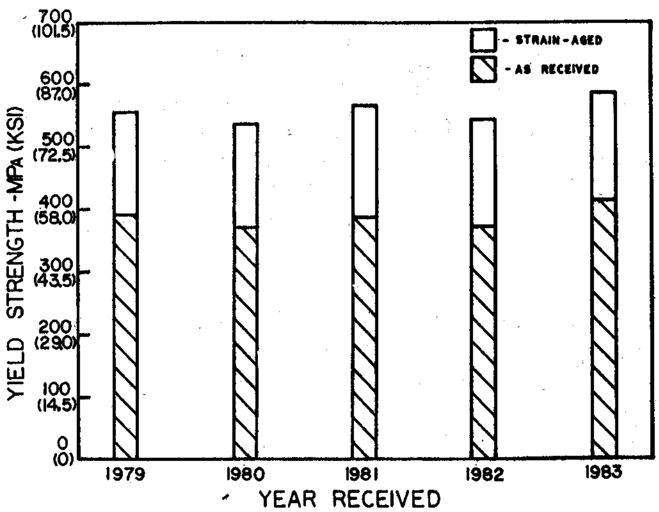


FIG. 8 UNIFORMITY OF GM980X

Fig. 8 shows average yield strengths of materials received in the last five years. All of this steel is from one source and it shows little variation by year in both the "as-received" condition and after strain aging. It also shows that the yield strength of "as-received" material, properly annealed intercritically, can be increased by 40% by suitable strain aging treatments.

	YIELD	TENSILE	ELONGATION
As Rec'd	345.0	586.0	28%
Strain Aged	580.0	634.0	20%

Chemistry: C .12, Mn 1.50, P .014, S .010
Si .65, Al .055, V .065, Zr .010
Ni .02, Cr .04, Mo .01

FIG. 9 TYPICAL DATA GM980X (3)

Fig. 9 shows typical chemical and mechanical data.

While GM980X steel for this application has been a single sourced item, other sources have indicated interest in developing their own product. We have received trial submissions from three additional sources. One trial was completely satisfactory, but good parts were not made from the other two trials. The major problems were low elongations that resulted in forming cracks.

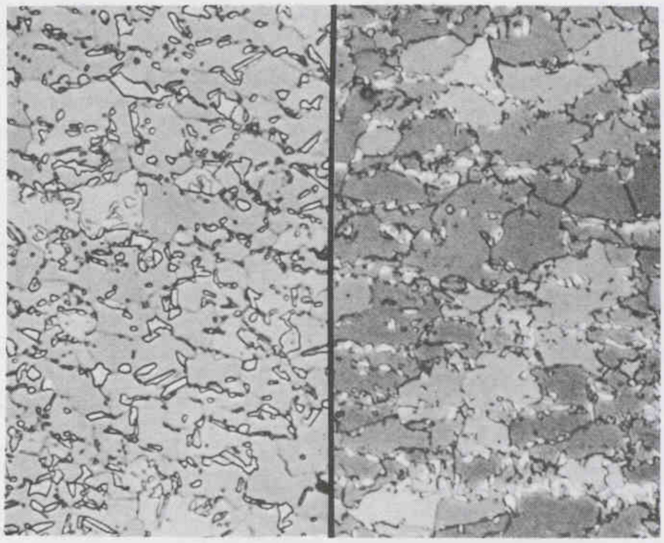
The production history of GM980X has been highly satisfactory with the source maintaining good uniformity and high quality levels. We do know the intercritical anneal that produces the dual phase microstructure has been difficult to maintain because of the very critical time, temperature, and cooling rates involved, as well as the chemical variation. Actually, this type of successful production development is the result of a good working relationship between supplier and customer. By permitting small changes in our processing, we have been able to use some out of specification material. For example, two heats were processed with a 288°C. age after test data showed that 163°C. was insufficient to reach 552MPa yield. We operate to a minimum elongation specification of 26% but several heats that showed 24% formed satisfactorily and were used.

You will be shown three examples of problems that have been encountered, along with the corrective actions that were employed. This steel is processed from ingots. Each ingot is made into one master coil which is the stage where the intercritical anneal is performed, and the master coils are annealed one at a time. Each master coil is slit into 13 multiples for our production use.

	COIL 723915 HEAT 959739	COIL 769806 HEAT 954164
As Rec'd		
Rb Hardness:	83.0	83.0
Yield MPa :	327.7	324.4
Tensile MPa:	587.6	556.0
%Elongation:	39.0	26.4
After Strain Age		
@163° Yield MPa:	513.2	564.7
@288° Yield MPa:	535.6	

FIG. 10 LOW YIELD STRENGTH IN ONE MASTER COIL OF HEAT 959739. COMPARE TO GOOD HEAT REF. FIG. 11

In one heat of 20 master coils, one of those coils showed low yield strength while all others were acceptable. The sample also showed low yield after 288°C. aging. Fig. 10 shows data on the low yield coil as compared to typical material.



TYPICAL LOW YIELD

FIG. 11 COMPARISON OF LOW YIELD VS TYPICAL GM980X

The differences in the microstructures of low yield and typical material are shown in Fig. 11. The low yield coil shows a generally coarser microstructure with more free Ferrite and the Martensite-Austenite particles are smaller. This suggests a different annealing temperature was used or possibly a slower cooling rate that permitted the transformation of Austenite to Bainite and Ferrite.

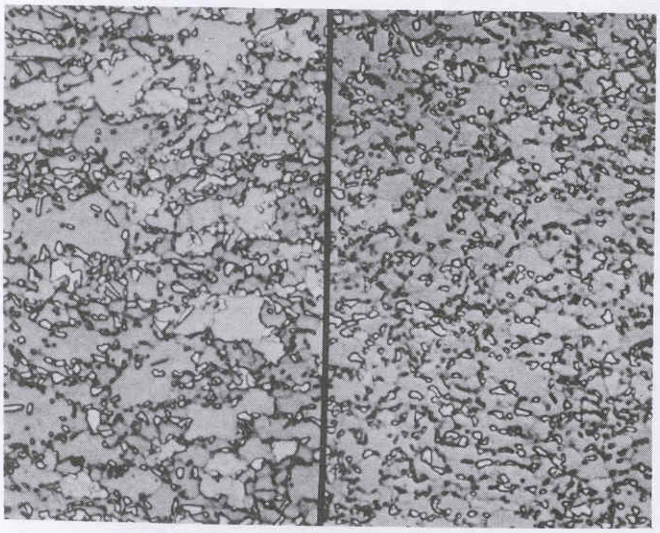
That is the reason for making tensile checks on every master coil. Because each coil is annealed individually and the intercritical anneal is responsible for the correct microstructure, it must be adequately monitored.

MASTER COIL 758679

	BACK	FRONT
Rb Hardness:	86.0	95.5
Yield MPa :	379.2	503.4
Tensile MPa:	630.4	704.8
%Elongation:	27.5	21.5

FIG. 12 SAME MASTER COIL WITH BOTH LOW AND GOOD ELONGATION
REF. FIG. 13

During processing of another shipment, we found one master coil with poor elongation at the front but towards the end of the coil, the elongation was good. The test data is shown in Fig. 12 and it shows significantly different hardness, tensile and yield results along with the low elongation. This same problem existed in all multiples from that one master coil. On the first parts run, cracks and splits were noted but as we progressed through the coil, all parts were acceptable. And that is why we check the front and back of each master coil.



HIGH 1000X LOW

FIG. 13 COMPARISON OF FRONT AND BACK OF SAME COIL SHOWING HIGH AND LOW ELONGATION

Fig. 13. The microstructures also show variations that indicate the annealing cycle was not uniform throughout the coil. Consistent with high yield material, the low elongation end of the coil shows more of the Martensite-Austenite phase and less Ferrite. In this case, the coarser microstructure formed satisfactorily. We have experienced some low elongation and cracking when the size, shape and distribution of the Martensite was similar to the Ferrite phase, but it was more extreme than this sample exhibits.

MASTER COIL 645098

As Rec'd	BACK	FRONT
Rb Hardness:	86.5	88.5
Yield MPa :	417.9	443.2
Tensile MPa:	620.5	671.1
%Elongation:	27.5	27.0
Strain Age at 163°C.		
Yield MPa :	593.8	629.4

FIG. 14 TEST DATA GOOD BUT CRACKED DUE TO MARTENSITE BANDING.
REF. FIG. 15

Fig. 14. On a third occasion, all tensile and elongation data looked good on all samples, but when the steel was used, a few forming cracks were observed of a type not typical of low elongation material.

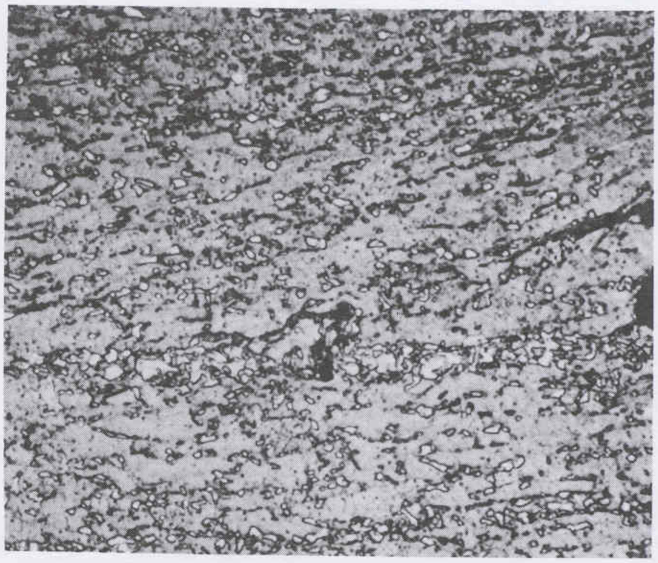


FIG. 15 MARTENSITE BANDING THAT CAUSED FORMING CRACKS 1000X

Fig. 15. The microstructure showed an abnormal amount of chemical banding as evidenced by areas of high percentages of Martensite. We concluded the cracking did occur as a result of this condition. Dispersive X-Ray probe analysis showed higher amounts of Manganese in the areas of cracking.

PLATING

When these steering reinforcements were introduced in 1975, the process called for a Zinc plate and a stress relief after forming. In 1975, the steel source moved the location of rolling to another mill where continuous galvanizing facilities were available. One trial lot indicated that galvanized steel had formability properties similar to non-galvanized steel. Since 1978 this part has been manufactured from galvanized steel with no problems associated with the coating. The 163°C. thermal treatment has been retained, but now it serves as the aging treatment instead of a stress relief.

SUMMARY

In summary, the unique features of GM980X steel has provided us with a new method of manufacturing critical parts. Productivity improvements, through cost reductions and quality gains, have been realized and we are in the process of releasing other parts of the same material.

REFERENCES

(1) Baxter, D. F., "GM Develops a Superformable HSLA Steel", Metal Progress, August 1977

(2) M. S. Rashid, unpublished data

(3) Jones & Laughlin Steel Corporation, unpublished data.