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Dual Phase Steel Production Bumpers

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General Motors Corp.

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IMPROVING FUEL ECONOMY THROUGH VEHICLE WEIGHT REDUCTION is currently a high priority activity in the automotive industry.

The bumper system, which took on a significant weight increase in 1973 (Fig. 1) as a result of the MVSS 215 Bumper Standard, was a good candidate for weight reduction. The bumper system weight is a function of the performance requirements, design, and material selection.

The choice of material is dependent on styling, appearance, weight, and cost. Today's bumpers are most often made of HSLA steel, aluminum, elastomers, or a combination of these materials. This paper evaluates the use of a dual phase HSLA steel for bumper face bars.

Higher strength steels can significantly reduce bumper weight, as shown in Fig. 2. Changing the face bar steel from a mild steel to SAE 980, while maintaining equal bumper performance with a corresponding gage reduction from .120" to .080", reduces the weight by 33%. The problem with current SAE 980 steel is that it has an elongation of only 18% and will not form the bumper shapes currently used at Cadillac.

Generally, an SAE 950 steel modified for increased formability and inclusion shape control, with elongations of 27-30% (referred to as SAE 950-M), was the highest strength steel that would form 1978 Cadillac bumpers.

In 1976 Dr. M. S. Rashid of G. M. Research reported the development of a new dual phase HSLA steel referred to as G. M. 980X steel. This steel, assigned the number G. M. 6187-M, has mechanical properties listed in Fig. 3 and shown on the stress-strain curve. At 0.2% offset the yield strength is 55 ksi maximum; at 3.0% offset the yield strength is 70 ksi minimum. The tensile strength is 90 ksi minimum and the elongation is 27% minimum.

This steel is basically an annealed vanadium strengthened SAE 980 steel.

Fig. 4 compares the stress-strain curves of G. M. 6187-M, SAE 980, SAE 950-M, and plain carbon steel. When G. M. 6187-M steel is strained greater than three percent in the forming process, the yield strength is increased to 70-90 ksi, or about the same as SAE 980. G. M. 6187-M dual phase steel has a stress-strain character-

ABSTRACT

The use of HSLA dual phase steel is an effective method of reducing bumper weight while meeting ever increasing government performance requirements. A paper analysis, followed by a hardware evaluation, successfully substituted "dual phase" for conventional HSLA steel at a reduced thickness. Bumpers for the all-new 1979 Cadillac Eldorado were designed and released using dual phase steel with yield strengths of 70-80 ksi for the face bars. Production problems were overcome by modifications of mechanical properties and increased development experience with this steel. To achieve the full work-hardening potential of dual phase steel, bumper sections and draw dies must be designed for a uniform strain greater than three percent.

Future dual phase steel for bumpers in the 80-120 ksi range is desirable, but further improvements in steel-making technology and part and die design techniques are required to achieve this goal.

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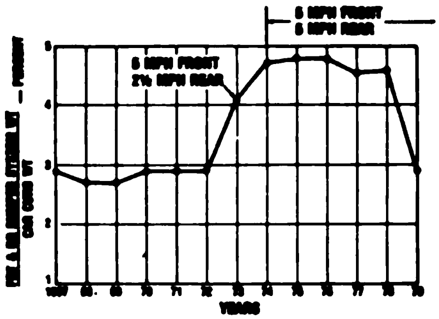

Fig. 1 - Eldorado front & rear bumper system weight as a percent of curb weight vs. years

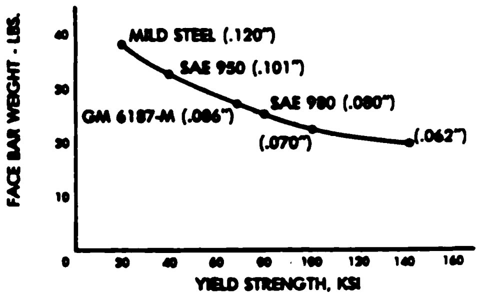

Fig. 2 - Bumper face bar weight vs. yield strength - 4,000 lb. car

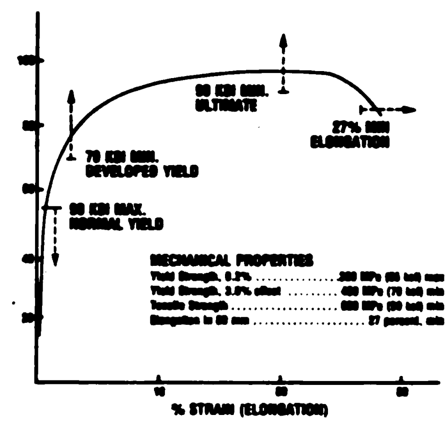

Fig. 3 - G. M. 6187-M mechanical properties and stress-strain curve

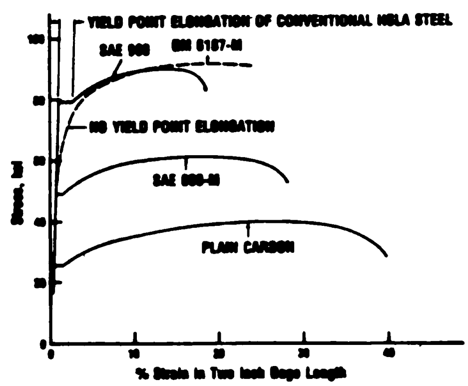

Fig. 4 - Stress-strain curves for plain carbon, SAE 950-M, SAE 980, and G. M. 6187-M steels

istic showing no yield point elongation which enhances formability.

These characteristics should provide the properties to form today's bumpers with good potential for gage and weight reduction. Several SAE papers have been presented describing the characteristics of G. M. 6187-M dual phase steel as listed in the references. This paper will describe Cadillac's experience as an end user.

ANALYSIS

Many steels were analyzed using a hypothetical bumper with equal bumper performance. A chart was compiled (Fig. 5) comparing the essential characteristics of some of these steels to SAE 950-M. G. M. 6187-M steel compared most favorably to the SAE 950-M steel and had the additional potential of reduced gage if the steel was strained greater than three percent in the manufacturing process. Based on this data, a hardware evaluation was initiated.

TRIAL RUN

A 1978 Eldorado rear bumper, made of SAE 950-M steel, was selected as the candidate for the G. M. 6187 tryout (Fig. 6). The gage was reduced from .111" to .101", and parts were made on production tools. These bumper bars were again evaluated for essential characteristics,

MATERIAL	ESSENTIAL CHARACTERISTICS							
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SAE 950	— BASELINE —							
SAE 950			X	X	X	X	X	5
SAE 950				X	X	X	X	4
GM 6187-M	X	X	X	X	X	X	X	7
MILD STEEL	X	X	X	X	X	X		6

Fig. 5 - Essential characteristics of a hypothetical bumper with various bumper steels compared to SAE 950

Fig. 6 - 1978 Eldorado rear bumper

	BUMPER	ESSENTIAL CHARACTERISTICS							
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	— BASELINE —							
a	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
b	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
c	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
d	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
e	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

Fig. 7 - Summary of essential characteristics of 1978 and 1979 Eldorado bumpers comparing SAE 950 to G. M. 6187-M

as shown in Fig. 7, line A. All of these characteristics were considered equal to the SAE 950-M material while achieving the desired weight reduction.

Although the surface of the formed parts appeared rougher than SAE 950-M, the chrome-plated parts had a quality appearance equal to SAE 950-M steel with the Cadillac plating system, which includes a copper plate and buff. Without the leveling contribution of the copper plate, the plating appearance of G. M. 6187-M was judged inferior to SAE 950-M steel. The bumper met all the requirements of Part 581 Bumper Standard. The yield strength of these bars is shown in Fig. 8. The upper surface yield strength was 89.3 ksi; however, the yield strength on the face ranged from 62.9 to 83.9 ksi. The section strength varied because of the bar shape and the conventional draw die design, as shown in Fig. 9. The front face of the bar was locked to the punch; consequently, most of the stretch occurred on the upper surface.

Material cost was a standoff with gage reduction from .111" to .101". The bar weight was reduced by 2.2 pounds. Since this trial run was considered successful by all concerned, G. M. 6187-M was released for mid-model production for the 1978 Eldorado rear bumper.

PRODUCTION RUN

With production lifts of steel, minor crack problems were observed in the area shown in Fig. 10. With the trimline modified, as shown by the dotted line in Fig. 10, production ran with acceptable scrap rates. This successful production run gave Cadillac greater confidence for expanded use of G. M. 6187-M for other bumpers. After the production tryouts, the chart of essential characteristics was updated to reflect the results of this run (Fig. 7, line B). This chart shows that G. M. 6187-M was judged slightly less formable than SAE 950-M because of the higher frequency of splits during forming.

The 1979 Eldorado was designed for the 4,000 pound EPA weight class for a 23% weight reduction from 1978. The 1979 front and rear bumper system weights were targeted for 118 pounds for a weight reduction of 52%. To achieve the 52% bumper weight reduction new technology and new materials were required. The 1979 Eldorado bumper design basically included a G. M. 6187-M steel face bar, a 7021 aluminum reinforcement, hydraulic energy absorbers, and bumper guards to provide a four-point barrier

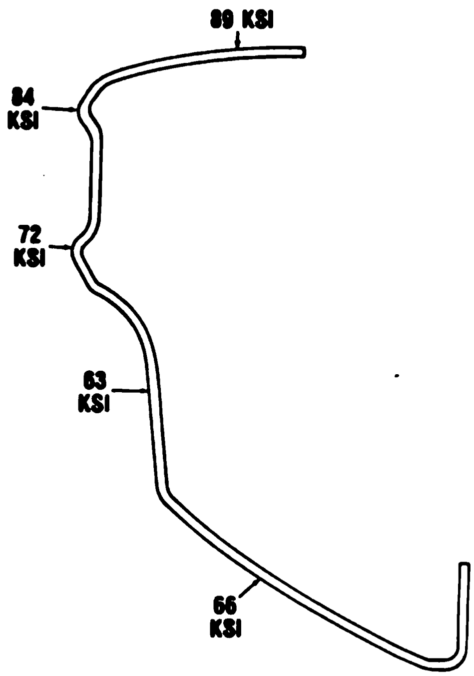

Fig. 8 - Yield strength of 1978 Eldorado rear bumper after forming with G. M. 6187-M steel

contact to minimize the bar bending moments (Fig. 11).

Preliminary stress analysis indicated that with G. M. 6187-M steel, a face bar thickness of .080" front and .087" rear was required. The bars were to be one piece, but after several unsuccessful die design attempts to achieve styling crispness on the outer ends, the bars were made in three pieces and welded together, as shown in Fig. 12.

The yield strengths of the prototype bars, shown in Fig. 13, were not uniform across the section. The top and lower surfaces achieved yield strengths of 101 and 97 ksi, respectively. The face yield strengths ranged from 57 to 84 ksi. With this section design the front surface becomes locked to the draw die punch (Fig. 14) causing the nonuniform stretch. As will be shown later, in order for G. M. 6187-M dual phase steel to achieve its full work-hardening potential either the part section design or the draw die design must provide for a uniform and adequate stretch.

The 1979 prototype bars were evaluated for essential characteristics, with results as shown in Fig. 7, line C.

The formability was judged slightly less formable than SAE 950, while the remaining characteristics remained equal or better than SAE 950. The bumpers met Part 581 bumper requirements with the calculated gages.

Fig. 15 shows the 1978 and 1979 Eldorado weight comparisons. The 1979 front and rear bumper system weights were 111 pounds, 7 pounds under target. At 111 pounds, the 1979 Eldorado bumpers accounted for 2.9% of the total car weight, a significant improvement over the corresponding 4.8% figure in the 1978 Eldorado.

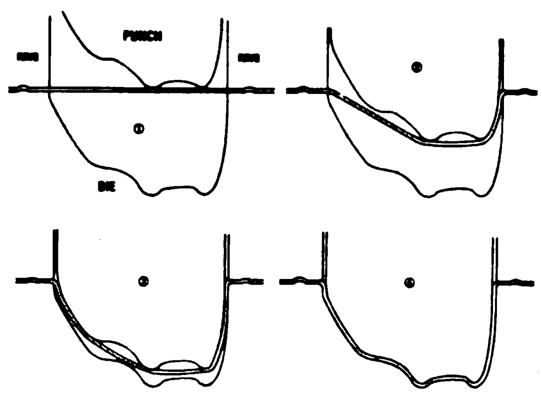

Fig. 9 - 1978 Eldorado rear bumper showing draw operation

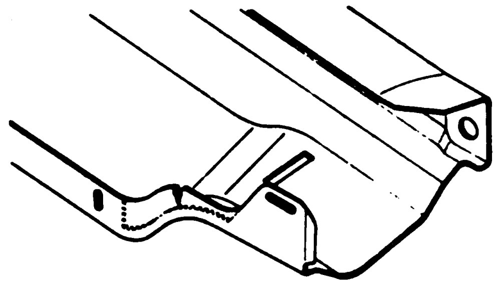

Fig. 10 - 1978 Eldorado rear bumper crack and trimline revisions

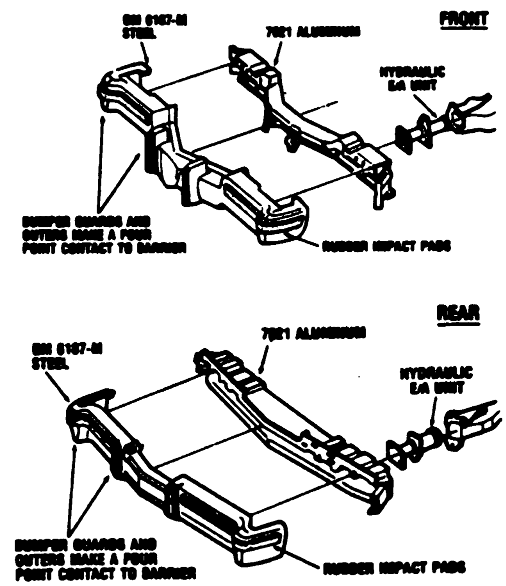

Fig. 11 - 1979 Eldorado bumper system design

Fig. 16 shows the bumper system weight versus vehicle weight on various 1979 cars. The bumper system weights are plotted corresponding to the most common material selection; i.e., all steel, all aluminum, and a combination of steel and aluminum. The 1979 Eldorado bumper weights, which represent a combination of steel and aluminum, are significantly below bumpers of similar construction.

A detailed weight analysis of the 1979 Eldorado bumper system is shown in Fig. 17. With this successful development program completed, G. M. 6187-M steel was released for 1979 production.

As with any revolutionary material, start-up problems were anticipated. Although steel suppliers have tighter controls on G. M. 6187-M steel than on conventional HSLA steels, the

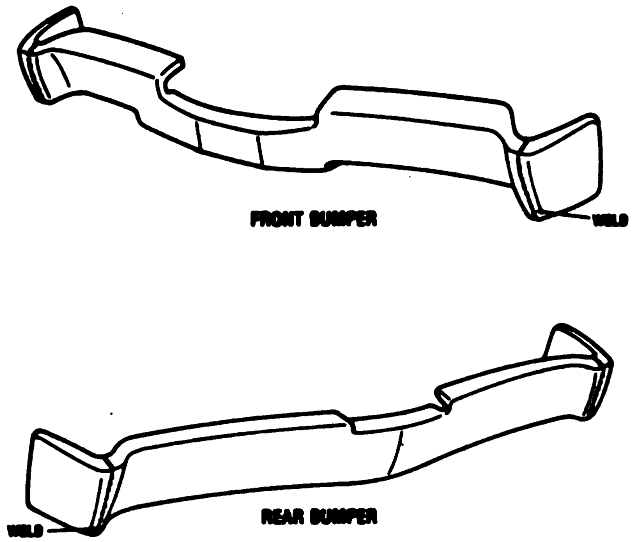

Fig. 12 - 1979 Eldorado bumper face bar construction

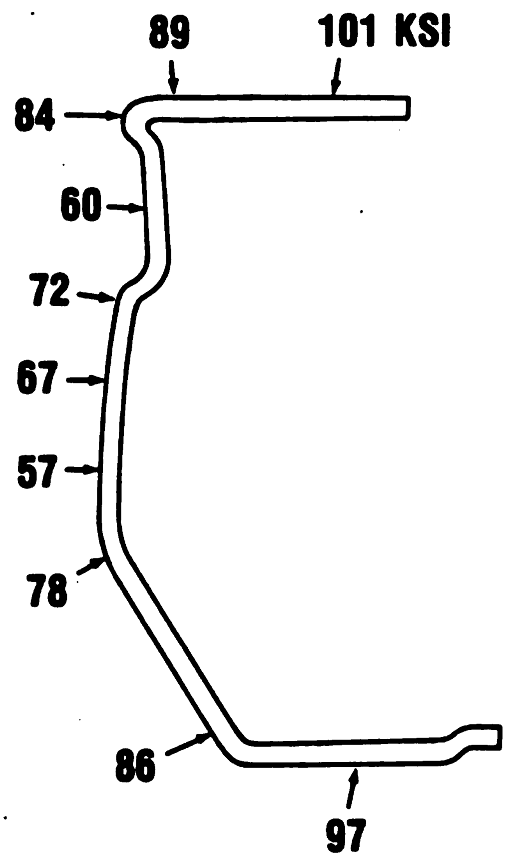

Fig. 13 - Yield strength on 1979 Eldorado prototype rear bumper section made from G. M. 6187-M steel

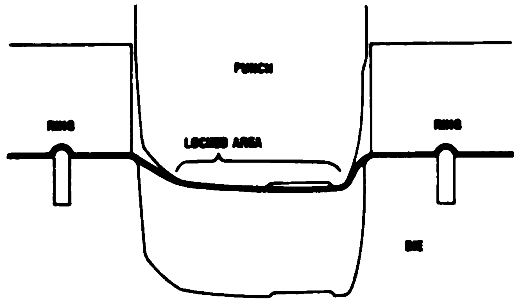

Fig. 14 - 1979 Eldorado rear bumper typical punch and die section

	1978 ELDORADO	1979 ELDORADO	1979 REDUCTION WEIGHT	%
TOTAL VEHICLE WEIGHT — LBS.	[illegible]	[illegible]	1101	[illegible]
FRONT BUMPER — LBS.	[illegible]	[illegible]	72	[illegible]
REAR BUMPER — LBS.	117	[illegible]	[illegible]	[illegible]
TOTAL FRONT & REAR	[illegible]	111	[illegible]	[illegible]

Fig. 15 - 1978 and 1979 Eldorado bumper system weight comparison

successful forming of this material requires good control of material properties, of lubrication, and of binder pressure; also, good die maintenance.

The strain values from the critical areas of the 1979 Eldorado rear bumper are plotted on a G. M. 6187-M forming limit diagram (Fig. 18). The strain values lie at or near a critical level of the curve. The bumper, from which these values were taken, had no indications of incipient failure; i.e., no necking, skin-splitting, etc. Any strain intensification or change in material properties, such as general lowering of the forming limit curve or anisotropic behavior caused by lack of inclusion shape or chemistry control, would move the press performance from the acceptable to the failure zone.

The chart in Fig. 19 shows the critical nature of the steel's mechanical properties to press performance during production runs of this material. The first run of bumpers, for all practical purposes, had no scrap.

The three percent strain yield strength and the tensile strength were below our original specifications. Bumper systems were validated for Part 581 Bumper Standard using this material.

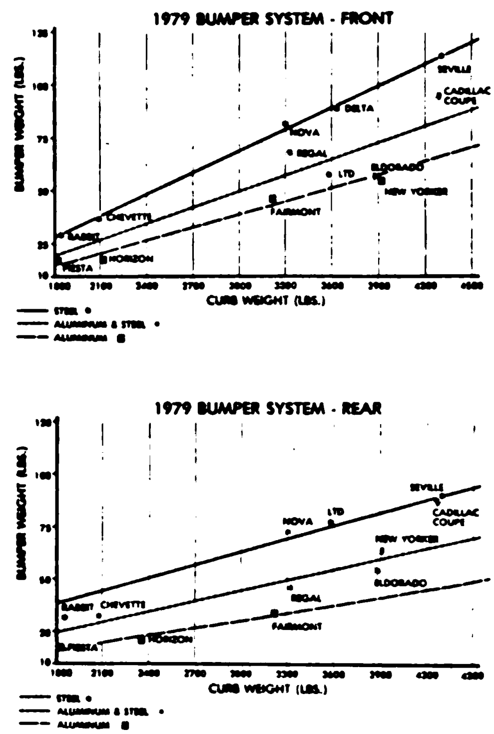

Fig. 16 - Bumper system weight vs. vehicle curb weight on 1979 cars

	WEIGHT — LBS. FRONT	REAR
IMPACT BAR	23.4	24.8
REINF. IMPACT BAR	7.5	8.2
ESCUTCHEON	1.5	.8
BUMPER GUARD	2.7	—
BUMPER GUARD — REINF.	1.9	—
IMPACT PADS	4.1	4.8
EA UNIT	8.2	8.2
EA BRACKET	.8	.8
DOUBLER PLATE	1.8	—
CORNER BRACKETS	1.2	1.2
BULKHEADS	.5	—
JACKING RESTRICTOR	—	2.8
FASTENERS	2.8	3.3
TOTAL	56.2	54.5

Fig. 17 - 1979 Eldorado bumper weight analysis

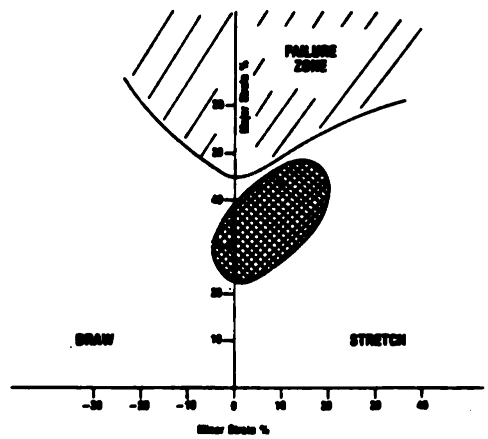

Fig. 18 - Strain values from critical areas of a 1979 Eldorado rear bumper plotted on a forming limit diagram for G. M. 6187-M steel

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
YIELD STRENGTH 0.2% OFFSET — KSI	[illegible] MAX	—	[illegible]	[illegible] MAX	[illegible]
YIELD STRENGTH 3.0% OFFSET — KSI	70 MIN	[illegible]	72/75	[illegible] MIN	[illegible]
TENSILE STRENGTH KSI	[illegible] MIN	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL ELONGATION %	27 MIN	[illegible]	[illegible]	[illegible] MIN	[illegible]
SCRAP	—	[illegible]	objectionable	—	acceptable

Fig. 19 - 1979 Eldorado rear bumper of G. M. 6187-M steel showing the effects of mechanical properties on scrap

Subsequent runs utilized material generally to specifications, but its press performance was much less desirable since the scrap rate increased to unacceptable levels. These runs were at times unstable with parts of lifts running with virtually no problems and other parts of a lift splitting every part. Parts split during the draw operation, as shown in Fig. 20, were scrapped. The mechanical properties for G. M. 6187-M were then modified, as shown in Fig. 21. The 0.2% offset yield strength remained at 55 ksi maximum. The three percent yield strength was lowered to 65 ksi minimum. The tensile strength was lowered to 85 ksi minimum. The total elongation was raised to 28% minimum.

The press scrap rate with the modified mechanical properties was decreased to an acceptable level. After-forming yield strength showed only a slight decrease with the modified mechanical properties, as shown in Fig. 22, and showed no change in Part 581 bumper performance.

Other forming problems encountered were back flange skin-splitting with a 2X thickness radius and edge splitting in license opening flange at the corner radius (Fig. 23). Each split was caused by consumed formability in areas highly worked during prior operations. The license opening cracks are repaired by welding. The back flange sking splits have been reduced to almost zero with the latest production run, due primarily to better inclusion shape control and modification of mechanical properties.

Although the surface finish of G. M. 6187-M is poorer than SAE 950 steel, chrome plating quality was equal using the Cadillac plating system which has copper preplating.

Some problems were experienced with backside plating adhesion. The backside did not

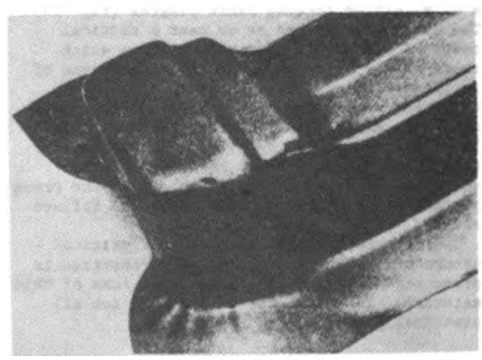

Fig. 20 - 1979 Eldorado bumper draw splits with out-of-spec. G. M. 6187-M steel

	ORIGINAL	REVISED
YIELD STRENGTH 0.2% OFFSET KSI	56 MAX	55 MAX
YIELD STRENGTH 3.0% OFFSET KSI	70 MIN	65 MIN
TENSILE STRENGTH KSI	90 MIN	65 MIN
TOTAL ELONGATION %	27 MIN	28 MIN

Fig. 21 - Mechanical properties of G. M. 6187-M original and modified

clean as thoroughly as other HSLA steels and resulted in a higher percentage of poor adhesion of the copper strike.

A more effective cleaning process was installed at Cadillac, and the steel supplied has an improved surface; consequently, this failure mode has been reduced to nil. Since the entire backside is 100 percent wax coated, the bumper has excellent corrosion protection.

Welding of G. M. 6187-M had no process related problems. Bumpers are welded using the MIG process with minor modifications for lighter gage steel. However, as the bumper gage is decreased, welding becomes more difficult.

The essential characteristic chart was updated to reflect the 1979 production runs (Fig. 7, line D and E). This chart shows that G. M. 6187-M steel with original mechanical properties is less formable than SAE 950-M steel, but has equal formability with revised mechanical properties. Other characteristics are the same.

More effective use of the work-hardening potential of G. M. 6187-M steel can be accomplished with better bumper or die designs. A section which provides for greater than three percent strain is essential. A computer program written to analyze the strain of bumper sections will provide the Design Staff Studio with design direction early in the styling phase. A modified bumper section is shown in Fig. 24 with design features to help avoid locking the bumper to the face of the punch and to provide for more uniform strain and higher yield strengths.

Techniques are possible in draw die design that can increase stretch and avoid locking the bumper to the punch face. One method is shown in Fig. 25. The bottom flange is opened permitting more stretch across the entire bumper section. This flange can be reformed in a subsequent operation. When designing dies for dual phase steel, uniform stretch must be a design requirement.

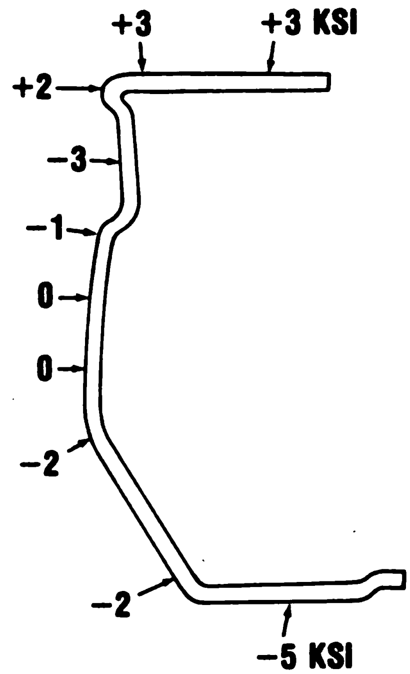

Fig. 22 - Yield strength change with modified as compared to original mechanical properties of G. M. 6187-M steel

FUTURE CONSIDERATIONS

What role will dual phase steel play in the future? There is still much to be learned about the steel-making process and the forming of this unique material. We have successfully made dual phase steel bumpers in the 80 ksi range; however, to achieve its full work-hardening potential, improvements in bumper and die design are required. The next step is to increase the three-to-five percent offset yield strength to the 80 to 120 ksi level. To accomplish this goal, the following objectives must be achieved:

From the steel mills -

- Eliminate inclusions or establish good distribution and shape control of inclusions.
- Optimize chemistry and processing.
- Provide good control and consistency of mechanical properties.

From the user -

- Design parts and dies to provide for strains between 5 and 15% in desired areas, but never exceed 25%.

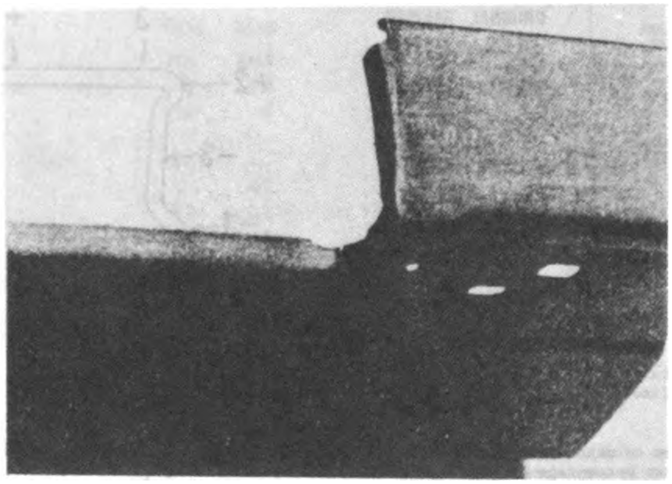

Fig. 23 - Edge splitting in license opening flange with G. M. 6187-M steel

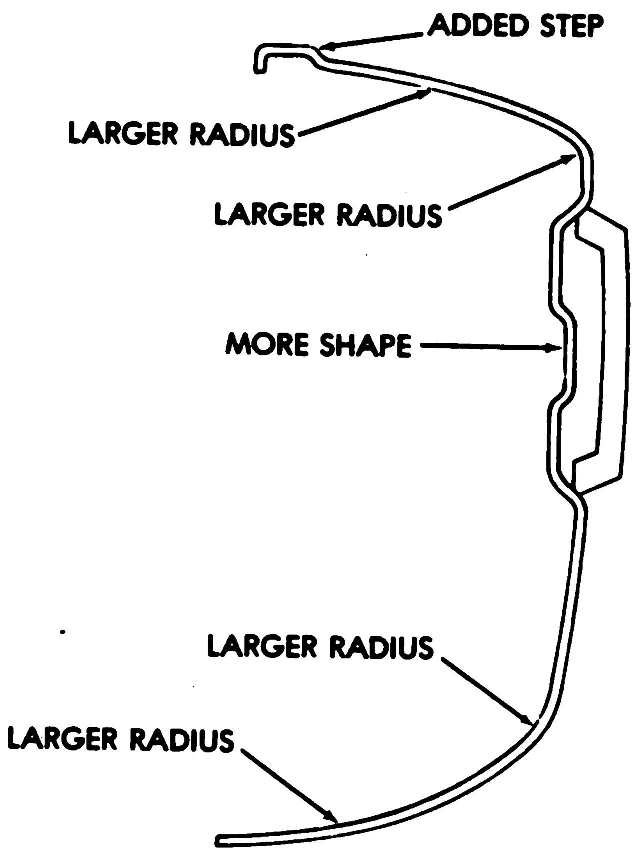

Fig. 24 - Bumper design modifications to increase yield strengths when forming dual phase steel

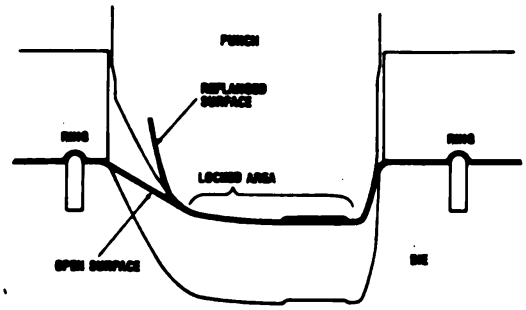

Fig. 25 - Proposed die change to increase strain when forming dual phase steel

- Improve die lubricants.
- Provide good die maintenance.
- provide proper binder pressures.

With the attainment of these objectives, higher yield strength dual phase steel at thinner gages is possible for bumpers and other automotive parts. This is the type of development needed to provide the lighter weight cars that will help to meet the mandated fuel economies of the 1980's.

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