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WHAT DRIVES SPACECRAFT COST: A LOOK INTO HOW MATERIAL CHARACTERISTICS RELATE TO THE MATERIAL COMPLEXITY MULTIPLIERS

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INTRODUCTION

Today a variety of engineered materials are used to build the space vehicles and satellites that NASA, DOD and the aerospace community will use in future projects. These materials can be a significant part of the cost when designing and building these systems. Current cost models such as NASCOM, SEER-H and PRICE allow the cost analysis to select materials requirements during the development of the cost model. It should be notes however that some of these models do not always give the most detailed information with respect to material specifications for the given cost model. Instead the materials are defined within broad classification, giving questionable data with regard to specific material cost. It is the objective of this paper to present a summary of basic information on materials to assist the cost analyst in the development of their models. Specificity this paper will compare materials and their complexity multipliers to some specific material properties.

COMPLEXITY MULTIPLIERS & PROPERTIES

For many years there has always been an attempt to correlate the cost of materials with some factor or factors. These factors can range from the material properties to material chemistry and composition and on to the actual manufacturing process itself.

Much work has been done to assist the cost estimator in the development of an accurate cost model. One item that is use are material complexity multipliers. Theses multipliers give the cost estimator a picture of how materials compare with each other with regard to their relative cost. One interesting question is "What Dives the Large Cost Difference?" Using material complexity multipliers generated for ramjet structures (NASA Report #CR-194428 p.54) this paper compares 1, density and the multipliers. 2. tensile strength and the multipliers and 3. Brinell hardness and the multipliers.

Figure 1 shows the comparison between density and the multipliers. Density was selected because weight is and important factor in aerospace design. Data from this comparison shows no relationship to the cost multiplier. One example is seen prominently. Three types of steel are shown, all have the same density yet the multiplier range from 1.6 to 3.4.

Figure 2 shows the comparison between tensile strength and the multipliers. It can be seen in this chart that there is some relationship between the tensile strength of the and material complexity multiplier. Once again if we look at steel as tensile strength increases the multiplier increases. This is also seen when it come to Nickel bases alloys. There are three Nickel based materials shown in this chart. 1. Nickel 2. Inconel and 3. Haynes. These three do have some strength difference and as their strength goes up so does the multipliers.

Finally Figure 3 compares material hardness and the multipliers. The number of materials compared was reduced because of the lack of data points available. The information

seen on this chart is similar to that of the tensile strength chart. As hardness goes up so does the cost multiplier. If we look at the three Nickel based alloys however we have very similar hardness but the differences in the complexity multipliers is very great.

RECOMMENDATIONS

From this data we can see that their is some correlation between strength and hardness to the material complexity multipliers. But within the Nickel based alloys group the question needs to be asked again Why the Large Cost Difference? Even for some of the other materials there are large difference in the multipliers. These difference, between similar materials and the multipliers need some further investigation to assist the cost estimator in producing accurate cost models. It is the recommendation of this study to look at other factor that may or could influence these large differences. The recommended areas for further investigation of the complexity multipliers are as following:

1. The actual material chemistry compared with the complexity multipliers.
2. The application of the materials compared with the complexity multipliers.
3. The manufacturing process used compared with the complexity multipliers
4. Material maturity compared with the complexity multipliers.

CONCLUSIONS

These four areas should help to establish what factors influence the material complexity multipliers to most. We have seen in this paper the relationship between some material properties and the material complexity multipliers for ramjet structures. We have seen from this that the complexity multipliers are not driven by just material properties and that there must be other factors at work. finally recommendations have been given for future work to help determine these factor and assist the cost estimator in producing the most accurate cost model.

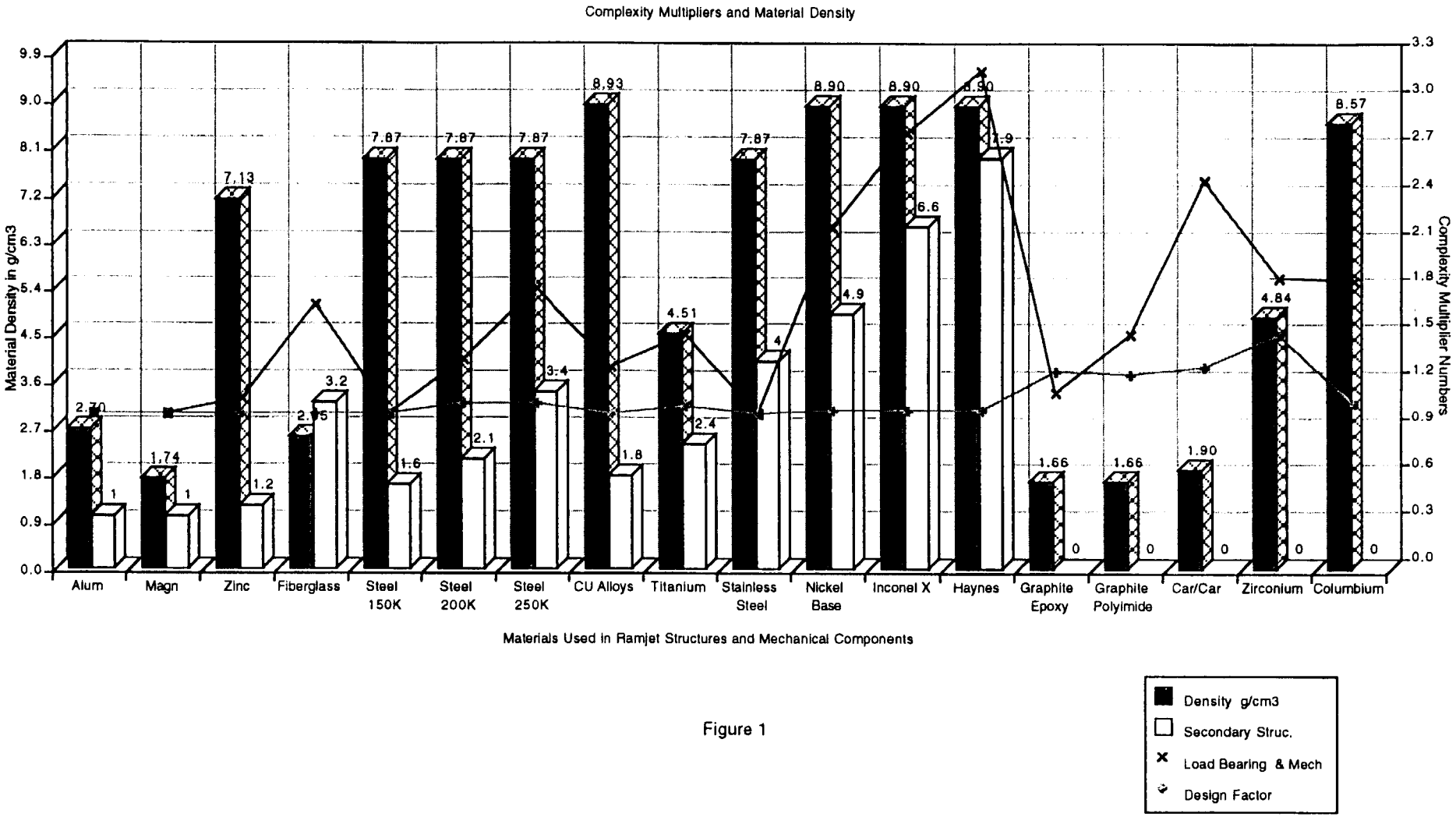
Complexity Multipliers and Material Density
Material Density in g/cm3
Complexity Multiplier Numbers
9.9
9.0
8.1
7.2
6.3
5.4
4.5
3.6
2.7
1.8
0.9
0.0
3.3
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0.0
2.70
1
1.74
1
7.13
1.2
2.75
3.2
7.87
1.6
7.87
2.1
7.87
3.4
8.93
1.8
4.51
2.4
7.87
4
8.90
4.9
8.90
6.6
8.90
7.9
1.66
0
1.66
0
1.90
0
4.84
0
8.57
0
Alum
Magn
Zinc
Fiberglass
Steel 150K
Steel 200K
Steel 250K
CU Alloys
Titanium
Stainless Steel
Nickel Base
Inconel X
Haynes
Graphite Epoxy
Graphite Polyimide
Car/Car
Zirconium
Columbium
Materials Used in Ramjet Structures and Mechanical Components
Density g/cm3
Secondary Struc.
Load Bearing & Mech
Design Factor

Figure 1

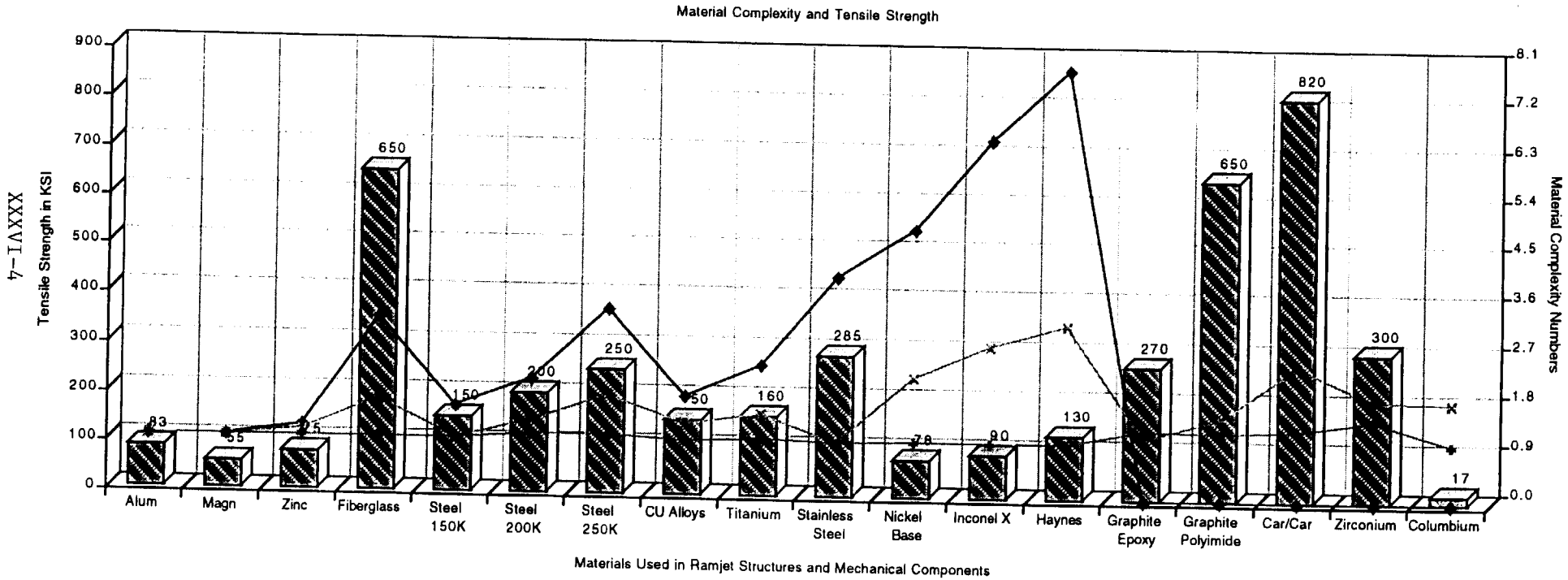
Material Complexity and Tensile Strength
Tensile Strength in KSI
Material Complexity Numbers
900
800
700
600
500
400
300
200
100
0
8.1
7.2
6.3
5.4
4.5
3.6
2.7
1.8
0.9
0.0
83
55
75
650
150
200
250
50
160
285
78
90
130
270
650
820
300
17
Alum
Magn
Zinc
Fiberglass
Steel 150K
Steel 200K
Steel 250K
CU Alloys
Titanium
Stainless Steel
Nickel Base
Inconel X
Haynes
Graphite Epoxy
Graphite Polyimide
Car/Car
Zirconium
Columbium
Materials Used in Ramjet Structures and Mechanical Components
Tensile Strength
Secondary Struc.
Load Bearing & Mech
Design Factor

Figure 2

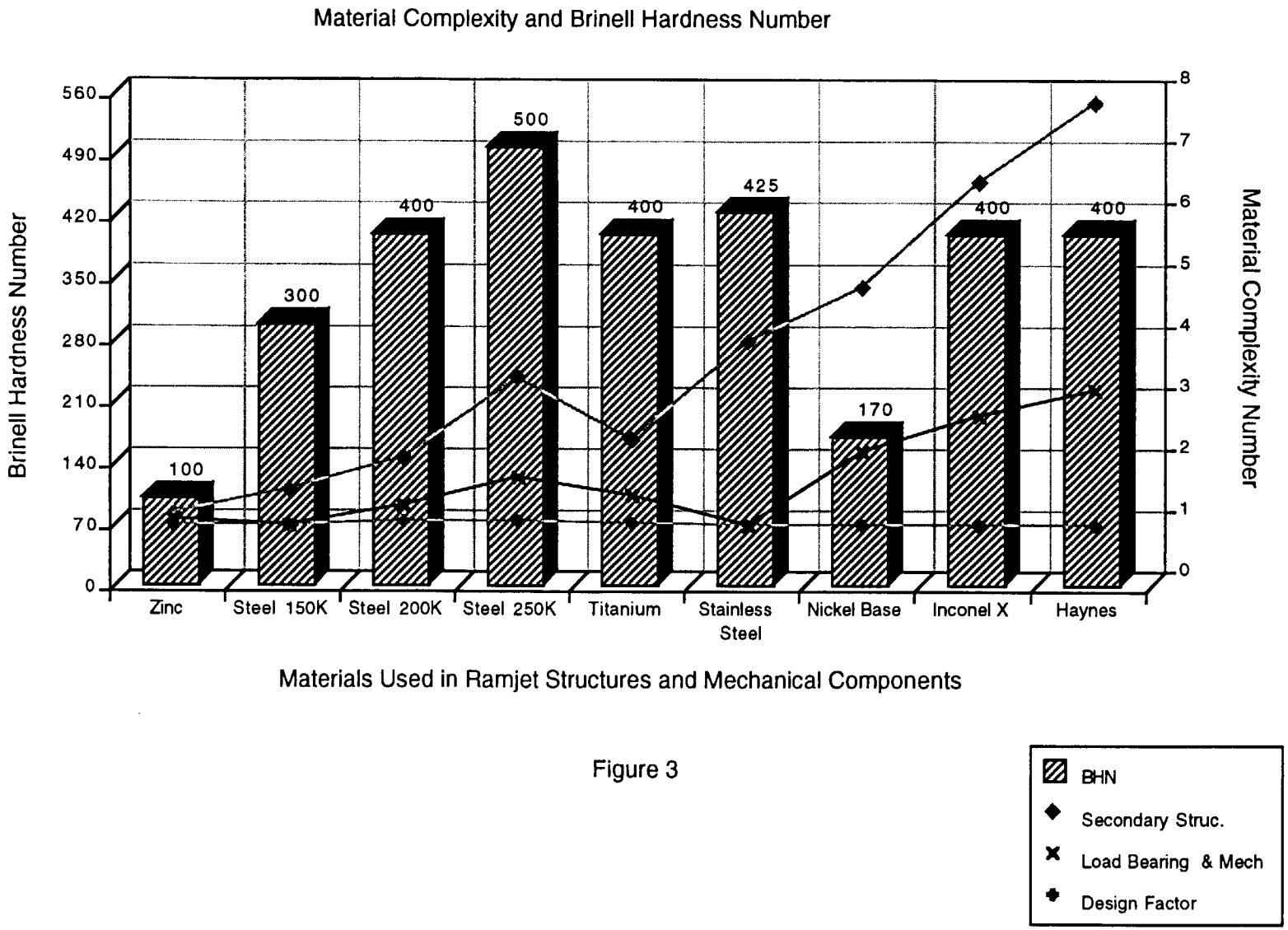
Material Complexity and Brinell Hardness Number
Brinell Hardness Number
Material Complexity Number
560
490
420
350
280
210
140
70
0
8
7
6
5
4
3
2
1
0
100
300
400
500
400
425
170
400
400
Zinc
Steel 150K
Steel 200K
Steel 250K
Titanium
Stainless Steel
Nickel Base
Inconel X
Haynes
Materials Used in Ramjet Structures and Mechanical Components
BHN
Secondary Struc.
Load Bearing & Mech
Design Factor

Figure 3