Development of Web-based Metal Property and Metal Information Databases

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Introduction

In modeling metal forming processes such as rolling, forging and extrusion, one of the most critical factors to achieve high prediction accuracy is to enter accurate metal property data such as flow stress and physical properties (specific heat, thermal expansion coefficient, thermal conductivity, Modulus of Elasticity, and Poisson Ratio, etc.). Increasing degree of process automation and computer application in the manufacturing industry has led more and more process modeling to be integrated into production operation. For example, in the steel rolling, especially the flat rolling, the use of Level 2 model to create instant draft schedule for compensating any variation of rolling conditions (e.g. slab temperature and slab dimension) has become a common practice. Draft scheduling is mainly based on rolling process modeling such as determining roll separating force, temperature, roll deformation and metal flow in the roll gap, etc. The high requirements for equal deformation targets, metallurgical temperature targets and high productivity targets, etc. in such a complicated process involving both roll deformation and metal flow, are far beyond operator's knowledge, and therefore, a computer model (Level 2 model) is of great help to operators. Today, process modeling is not a theoretical concept any more; it has since long become a manufacture-operational practice. Prediction accuracy has very high impact on the production performance. For example, for many steel plate mills (often with an annual sales of 800 million US dollars), an increase of force prediction accuracy of 1% often has an economic value of 1 million US dollars per year! [1]

Most hot-forming models, either offline or online ones, have considered flow stress as a function of temperature, strain and strain rate, though problems involving high-level understanding of the flow stress still occur, such as formula valid range, balance between accuracy and robustness, and metallurgical effects (especially when warm forming is involved) [2][3]. High quality flow stress data and model will greatly increase force prediction accuracy. In this aspect, Metal Pass' practice of the Guided Two-Parameter Learning [2][3], by accurate designing flow stress coefficients and applying them in the adaptive learning, usually achieves a high accuracy with force prediction error below 5%.

In comparison with the flow stress, the material property data are often greatly simplified in most models. For example, the material properties are usually entered as constant values and so, temperature dependence for them is usually ignored. Temperature dependence of metal property could be significant; so in certain situation the value of specific heat, for example, could be doubled from one forming temperature to another. A prediction model with too much simplification will heavily reduce its quality and reach only a limited accuracy. See discussion in the “High-Temperature Properties” section.

Even in the room temperature, material data are different from grade to grade. Many systems use the same property values for all grades of steels and cause system errors.

Metal Pass has collected a great number of metal property data and models, and posted them in the website metalpass.com, in order for development and design engineers to improve model quality. The property databases hosted in the metalpass.com currently consist of three sections: Flow Stress (metalpass.com/flowstress) [4], High-Temperature Property (metalpass.com/hit) [5] and General Property (metalpass.com /general) [6].

As one of the largest metal technology networks, metalpass.com also hosts technical information databases, such as Metal Dictionary - Tech Terms, Metal Dictionary - Translation, and Metal Software. Metal Pass also categorizes and posts a great number of industry patents, and provides over 50,000 supply listings for technical products and services. As extensions of the information databases, over a thousand pages of short papers and dozens of software programs are available.

In this paper, primary attention is paid on the metal property databases, though the key features of the metal information databases are also outlined.

Metal Property Databases

The metal property databases described here include the High Temperature Properties and General Properties of metals in the room temperature. The flow stress database, as one of the major properties of metal in hot forming, is only summarized here and will be further expanded in a separate section.

In order for user to easily access the technical data, Metal Pass provides shortcut web addresses for the major databases. Metal Pass has near 200 domain names that serve as shortcut URLs or address for satellite websites, see www.metalpass.com/services/shortcuts.aspx. A satellite website is a website focusing on a given topic but eventually links into the main site www.metalpass.com. As examples, www.metaldata.com links to the Databank, which the metal property databases belong to, and www.flowstress.com leads to the cover page of flow stress database.

Flow Stress

Flow stress is a primary metal-property critical in determining load and power requirements during metal forming processes (rolling, forging, and drawing, and so on). For easy application of the flow stress data, the database provides coefficient values for various models. Flow stress models provided in current access to metalpass.com are showed in the **Table 1**. The model types showed in the table may be briefly explained as follows:

- Model F2: An accurate strain-stress equation for each given temperature and strain rate.
- Model F2F3: An accurate equation for each temperature, which describes influences of strain and strain rate.

- Model F2F3a: A simple equation for each temperature, which describes influences of strain and strain rate.
- Model A: A model for describing influences of material, temperature, strain and strain rate in a single formula.
- Model B: A modification to the Model A with more accurate strain factors.
- Model C: A modification to the Model B with more accurate strain rate factors.

Table 1: Flow stress models provided at present

Material	Process	Model				
Steel and Ferrous Alloys	Hot Forming	F2	F2F3	A	B	C
	Cold Forming	F2	F2F3a	-	-	-
Nonferrous Materials	Hot Forming	F2	-	A	B	C
	Cold Forming	F2	F2F3a	-	-	-

Details on the data and the models will be discussed in a separate section.

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Flow Stress Databases

It is inconvenient to use direct flow stress values in each strain, strain rate and temperature, so the flow stress data is supplied with various models in which the model coefficients are provided together with the error of the formula against the original values.

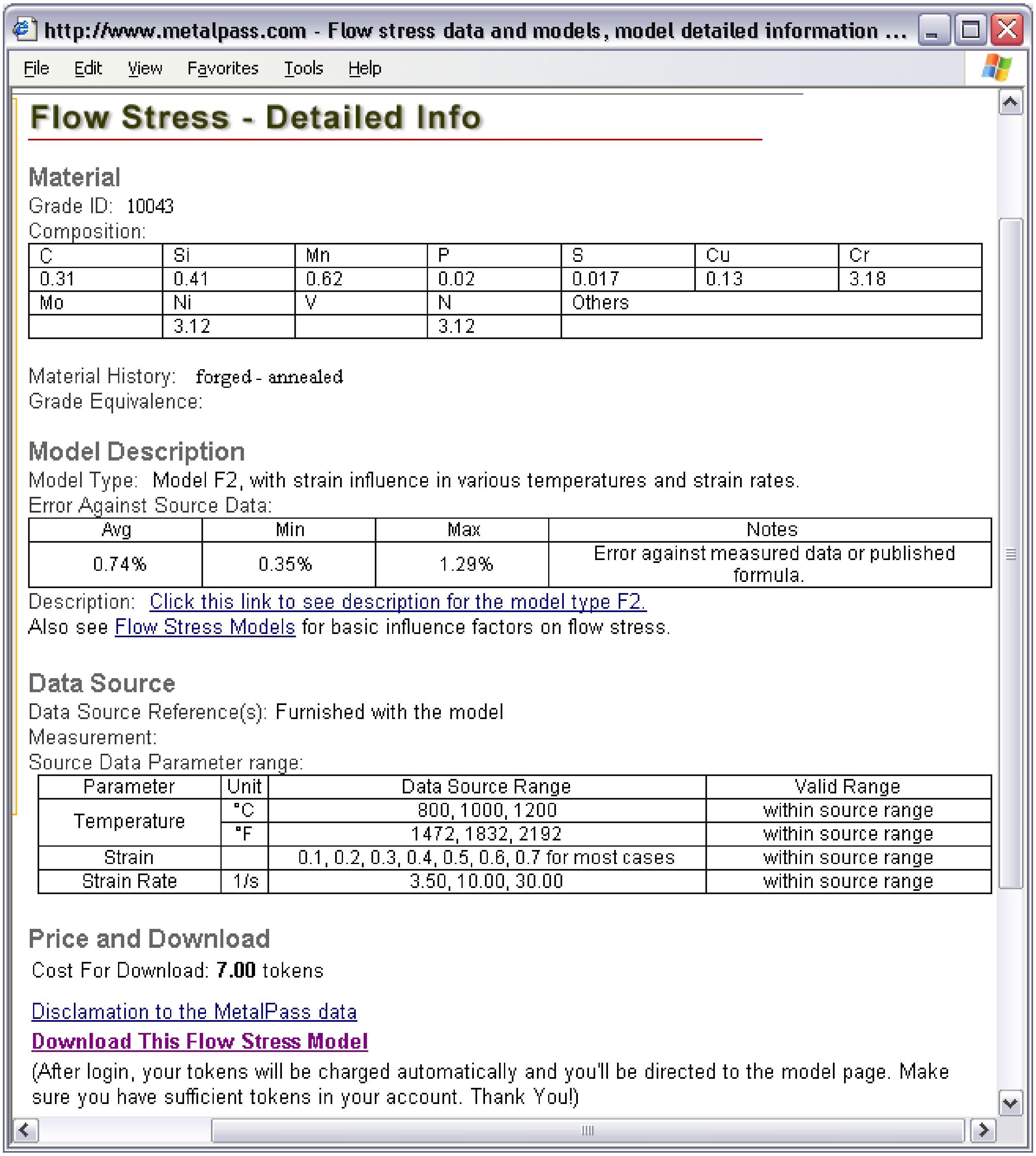
Model and Database Category

In the **Table 2** below the flow stress formulas are provided. In this table, T is temperature in ℃, except in the model A1 in which T is in K. φ is strain, and U is strain rate in 1/s. A_1 and m_1 are temperature coefficients, A_2 and m_2 (and also m_4 if available) are strain coefficients, and A_3 and m_3 (together with m_5 if available) represent strain rate coefficients. In the following paragraphs, each model used in the database is described.

Table 2 Flow stress equations used in the database

Name	Equation
F2	$K_f = K_{f2} \varphi^{m_2} e^{m_4/\varphi}$
F2F3	$K_f = K_{f0} \cdot A_2 \varphi^{m_2} e^{m_4/\varphi} \cdot A_3 U^{m_3}$
A	$K_f = K_{f0} \cdot A_1 e^{-m_1 T} \cdot A_2 \varphi^{m_2} \cdot A_3 U^{m_3}$
B	$K_f = K_{f0} \cdot A_1 e^{-m_1 T} \cdot A_2 \varphi^{m_2} e^{m_4/\varphi} \cdot A_3 U^{m_3}$

C	$K_f = K_{f0} \cdot A_1 e^{-m_1 T} \cdot A_2 \varphi^{m_2} e^{m_4/\varphi} \cdot A_3 U^{m_3 + m_5 T}$
F2F3a	$K_f = K_{f0} \cdot A_2 \varphi^{m_2} \cdot A_3 U^{m_3}$
A1	$K_f = C_1 e^{C_2/T} \cdot \varphi^{C_3} \cdot u^{C_4}$



http://www.metalpass.com - Flow stress data and models, model detailed information ...

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Flow Stress - Detailed Info

Material

Grade ID: 10043

Composition:

C	Si	Mn	P	S	Cu	Cr
0.31	0.41	0.62	0.02	0.017	0.13	3.18
Mo	Ni	V	N	Others		
	3.12		3.12			

Material History: forged - annealed

Grade Equivalence:

Model Description

Model Type: Model F2, with strain influence in various temperatures and strain rates.

Error Against Source Data:

Avg	Min	Max	Notes
0.74%	0.35%	1.29%	Error against measured data or published formula.

Description: Click this link to see description for the model type F2.

Also see Flow Stress Models for basic influence factors on flow stress.

Data Source

Data Source Reference(s): Furnished with the model

Measurement:

Source Data Parameter range:

Parameter	Unit	Data Source Range	Valid Range
Temperature	°C	800, 1000, 1200	within source range
	°F	1472, 1832, 2192	within source range
Strain		0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7 for most cases	within source range
Strain Rate	1/s	3.50, 10.00, 30.00	within source range

Price and Download

Cost For Download: **7.00** tokens

Disclamation to the MetalPass data

Download This Flow Stress Model

(After login, your tokens will be charged automatically and you'll be directed to the model page. Make sure you have sufficient tokens in your account. Thank You!)

Figure 3 Detailed Information screen for the model type F2

Model F2. Many sources of the published flow stress are based on flow stress curves, such as [7], but the user needs actual data instead of curves. For this reason, Metal Pass has developed a program to measure the flow stress data from curves and deliver the result with this model. This form can well describe the peak flow stress during hot forming and is with very high accuracy. For each temperature and strain rate, a set of values K_{f2}, m_2 and m_4 are given, and the error from this model is only about 0.3% for most data.

Model F2F3. If the strain rate factors are put into the formula, equation for the model F2F3 is created, in which K_{f0} is the reference stress. For each temperature, a set of values A_2, m_2, m_4, and A_3 and m_3 are given besides K_{f0}. The error calculated from this model is also as low as 0.3% for most data.

Model A. As a classic flow stress formula, this equation provides a simple way to describe flow stress, in which K_{f0} is the reference stress and equivalent to a stress value of a reference condition, e.g., strain 0.3, temperature 1000 ℃ and strain rate 10/s.

Model B. If the strain is in a large range, or if there is softening that causes peak flow stress, the formula for the Model B is preferred. This formula may be valid for a strain range 0.05 to 1.5.

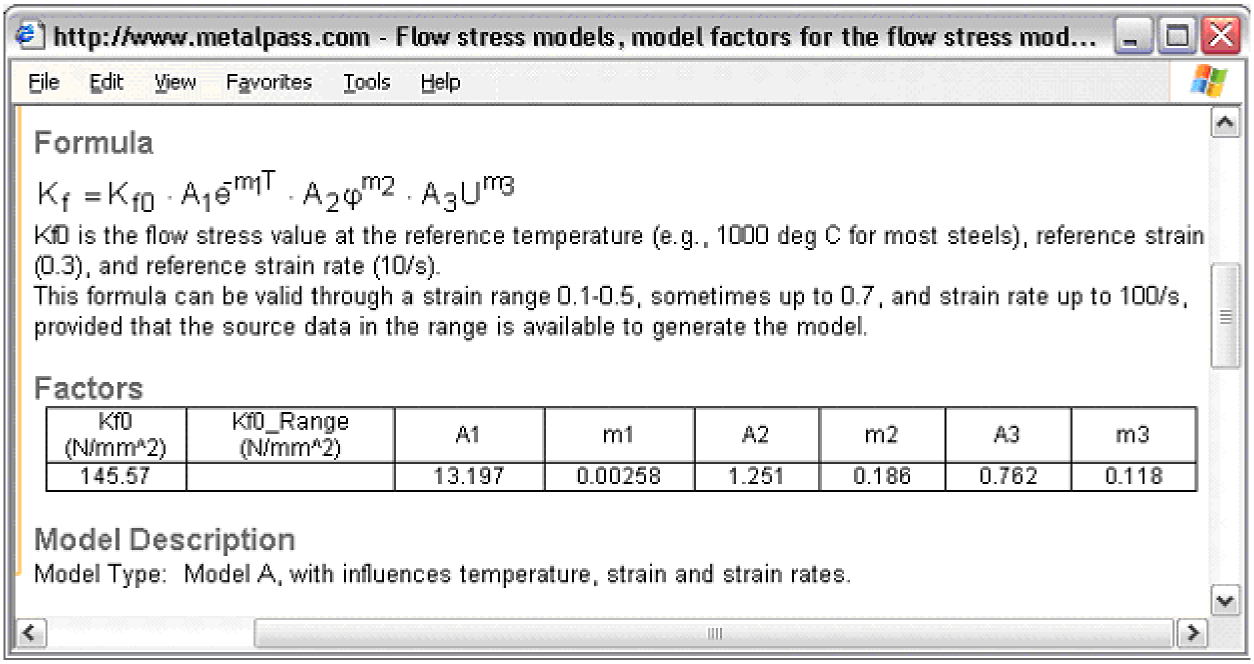
Model C. For high-speed rolling, due to the large strain rate range, the formula of Model C is preferred, in which a temperature dependent factor m_3+m_5*T is used for the strain rate coefficient. The strain rate valid range is up to 500/s, applicable through 3000/s.

Model F2F3a. In many cases, the Model F2F3 can be simplified into the Model F2F3a. This formula can be used to describe measured flow stress data with relatively narrow strain and strain rate range. It may be used for both hot forming and certain cold forming.

Model A1. Some online models (level 2 models) use a simple Model A1 similar to the Model A, except for the temperature factor. The four coefficients, C_1, C_2, C_3 and C_4 are constants representing factors for material, temperature, strain and strain rate. Based on this formula, Metal Pass has developed over 6000 sets of flow stress coefficients to cover the entire steel grade range in a plate/coil mill. The data will soon be uploaded. The designed coefficients may be used as fixed value in the Guided Two-Parameter Learning [2][3] to achieve a high accuracy in force prediction.

This database is one of the most complete online collections for flow stress data and models. In the first phase over 1200 flow stress models for steels, metals, and ferrous and nonferrous alloys are available. The partial models F2, F2F3 and F2F3a, etc. deliver super accurate data. The full model A, B or C each provides a single formula for a given grade. As mentioned earlier, the flow stress database is accessible with www.flowstress.com, especially in the North America.

To be mentioned is that in the real metal forming force calculation, the mean flow stress is used instead of instant flow stress. This is because the forming process starts from strain 0 and ends with the final strain.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Formula

$$K_f = K_{f0} \cdot A_1 e^{m_1 T} \cdot A_2 \varphi^{m_2} \cdot A_3 U^{m_3}$$

Kf0 is the flow stress value at the reference temperature (e.g., 1000 deg C for most steels), reference strain (0.3), and reference strain rate (10/s).
This formula can be valid through a strain range 0.1-0.5, sometimes up to 0.7, and strain rate up to 100/s, provided that the source data in the range is available to generate the model.

Factors

Kf0 (N/mm^2)	Kf0_Range (N/mm^2)	A1	m1	A2	m2	A3	m3
145.57		13.197	0.00258	1.251	0.186	0.762	0.118

Model Description

Model Type: Model A, with influences temperature, strain and strain rates.

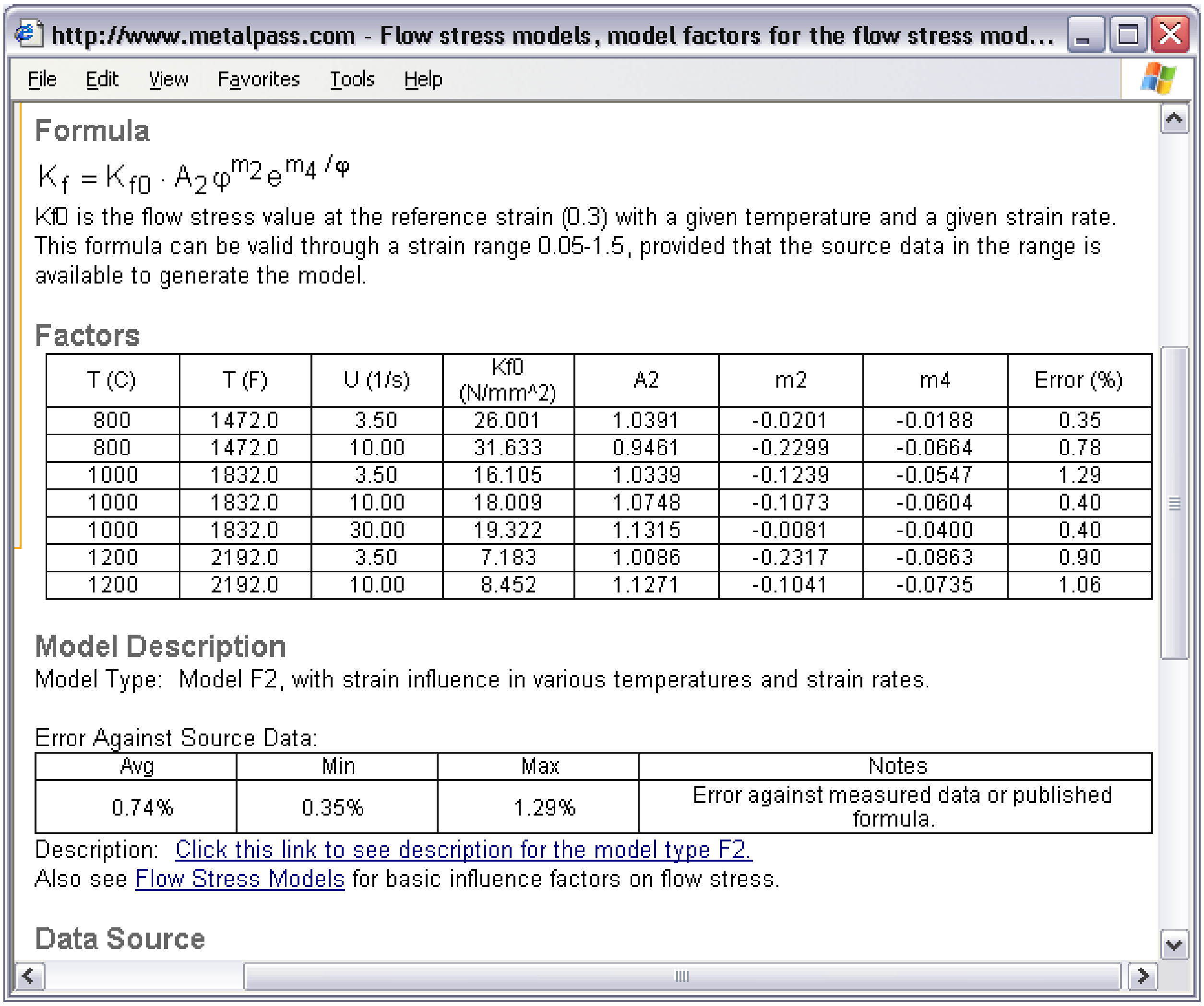
Figure4 Model page for the model type A

Database Interface

The first screen in accessing the flow stress database is the Grade List screen with short information such as grade name and primary chemical composition for each grade. In clicking on the "Detailed Info" link for a grade, the user is led to the Detailed Info screen (**Figure 3**). This screen provides user with information such as detailed chemical composition, material history, model type, model quality (error range if applicable), and data source ranges in temperature, strain and strain rate (if applicable). Contents for various model types may be different. This screen allows user to decide whether to proceed for data download.

The model screen requires login and with automatic deduction of account tokens. It is a summary screen, with model formula and all the formula coefficients provided, together with certain key information showed in the previous pages such as model description and data source. When user prints out this screen, the related information and data will all be available.

As examples, the model screens are showed for Model A (**Figure 4**) and Model F2 (**Figure 5**).


http://www.metalpass.com - Flow stress models, model factors for the flow stress mod...

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Formula

$$K_f = K_{f0} \cdot A_2 \varphi^{m_2} e^{m_4/\varphi}$$

Kf0 is the flow stress value at the reference strain (0.3) with a given temperature and a given strain rate. This formula can be valid through a strain range 0.05-1.5, provided that the source data in the range is available to generate the model.

Factors

T (C)	T (F)	U (1/s)	Kf0 (N/mm^2)	A2	m2	m4	Error (%)
800	1472.0	3.50	26.001	1.0391	-0.0201	-0.0188	0.35
800	1472.0	10.00	31.633	0.9461	-0.2299	-0.0664	0.78
1000	1832.0	3.50	16.105	1.0339	-0.1239	-0.0547	1.29
1000	1832.0	10.00	18.009	1.0748	-0.1073	-0.0604	0.40
1000	1832.0	30.00	19.322	1.1315	-0.0081	-0.0400	0.40
1200	2192.0	3.50	7.183	1.0086	-0.2317	-0.0863	0.90
1200	2192.0	10.00	8.452	1.1271	-0.1041	-0.0735	1.06

Model Description

Model Type: Model F2, with strain influence in various temperatures and strain rates.

Error Against Source Data:

Avg	Min	Max	Notes
0.74%	0.35%	1.29%	Error against measured data or published formula.

Description: Click this link to see description for the model type F2.

Also see Flow Stress Models for basic influence factors on flow stress.

Data Source

Figure5 Model page for the model type F2

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Summary

This paper introduces a list of web-based metal property and metal information databases accessible through metalpass.com. The property databases include Flow Stress, High-Temperature Property and General Property. The information databases consist of Metal Dictionaries (both Tech Terms and Translation), Metal Software, Metal Patents, and Metal Directory, etc. Primary focus is on the metal properties such as flow stress. Data for flow stress are provided with model coefficients. Model types and user screens for the flow stress database are described. Outlines for metal information databases were provided including the extensions of the information database with short papers and model-based software suites.

References

[1] B. Li and J. Nauman, Significance and development of a next-generation Level 2 model as a metallurgical system. *MS&T Conference, 2008.* October 5-9, 2008. Pittsburgh, PA., USA.

[2] B. Li, D. Cyr and P. Bothma: Level 2 Model Improvements at Evraz Oregon Steel Mills. *AISTech 2009*. May 4-7, 2009. St. Louis, Mo., USA.

[3] B. Li and J. Nauman: Metallurgical, modeling and software engineering issues in the further development of the steel mill Level 2 models. *AISTech 2008.* May 5–8, 2008. Pittsburgh, PA, USA.

[4] B. Li: Flow Stress. Online at *www.metalpass.com/flowstress*. Metal Pass LLC, Pittsburgh, PA, USA. Accessed in June 2009.

[5] B. Li: High Temperature Properties. Online at *www.metalpass.com/hit*. Metal Pass LLC, Pittsburgh, PA, USA. Accessed in June 2009.

[6] B. Li: General Properties. Online at *www.metalpass.com/general*. Metal Pass LLC, Pittsburgh, PA, USA. Accessed in June 2009.

[7] Suzuki, et al, *Studies on the Flow Stress of Metal and Alloys*. University of Tokyo. 1968.